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Examining Land Use/Land Cover Change and Potential Causal Factors in the Context of Climate Change in Sagarmatha National Park, Nepal

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EXAMINING LAND USE/LAND COVER CHANGE AND POTENTIAL CAUSAL FACTORS IN THE CONTEXT OF CLIMATE CHANGE IN SAGARMATHA NATIONAL PARK, NEPAL

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EXAMINING LAND USE/LAND COVER CHANGE AND POTENTIAL CAUSAL FACTORS IN THE CONTEXT OF CLIMATE CHANGE IN SAGARMATHA NATIONAL PARK, NEPAL

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I dedicate this thesis to my parents Keshav Prasad and Chitrakumari Humagain and my beloved wife Shova Pathak for their love and support.

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In the context of growing tourism and global warming, the fragile landscape of the Himalayas is under immense pressure because of rapid land cover changes in developing countries like Nepal. Remotely sensed data combined with ethnographic knowledge are useful tools for studying such changes. The quantitative change can be measured analyzing satellite images whereas local people's perceptions provide supportive information. To measure such changes in Sagarmatha National Park of Nepal, Multispectral Scanner (MSS) and Thematic Mapper (TM) images since 1972 were used. Normalized Difference Vegetation Index (NDVI) was calculated for different elevation classes and land cover types. These measurements, along with land cover change (1992-2006) analysis, shows a significant conversion of the areas covered by ice, shrub and grass to rock and soil. Factors including political conflict due to a Maoist rebellion group, inactive park management, increasing tourist demand, and consequent natural resources exploitation helped to explain the change in the forested areas. This is supported by the information from short, informal, semi-structured interviews with local people. However, the local people are unaware of global warming, which has caused the ice melting and glacial lake expansion. Although global causes are out of the immediate control of land managers, better management practices and managed tourism might help alleviate deteriorating Himalayan ecosystems.

CHAPTER 1: INTRODUCTION

1.1 Global climate change

The Earth's climate has always changed - with many warming and cooling cycles in the geologic record. Recently, however, anthropogenic influences have led to dramatic changes within the Earth system and, as a consequence, the planet is going through a rapid warming cycle associated with different outcomes such as sea-level rise, glacial melts, and unpredictable weather patterns. With the increase in industrialization and carbon-emitting activities, the effects of global warming are becoming more apparent, which has increased global concern. The majority of the scientific community believes that the Earth has experienced two recent warming periods, between 1910 and 1945 and from 1976 onwards, mainly because of the rise in greenhouse gases level (IPCC, 2001). In addition, results from the computer models, paleoecological studies of past climate change, and small-scale experiments reinforce the urgency of current rapid climate change.

It has been posited that mountainous areas probably are the parts of the Earth most affected by climate change, because they are already unstable due to biophysical and socioeconomic factors (Marston, 2008). In addition, mountains also represent unique areas for the detection of climatic change and the assessment of climate-related impacts, because temperatures change rapidly with altitude over relatively short horizontal distances (Benitson, 2003). The rise in global temperatures is already bringing change to the Himalayan glaciers and to regional precipitation patterns. With glacial melting, river flows may increase substantially and flood peaks may shift to earlier in the year. Some major effects of climate change include a raise in ambient temperature, an increase in average global precipitation, an increase in intensity of glacier retreat on the top of the mountains, a change in the habitat of flora and fauna, and a raise in global sea level (Korkeakoski, 2005).

Mountains are also one of the most vulnerable natural systems for climate change impacts because of significant anthropogenic activities (Marston, 2008). Relief, precipitation runoff, and human activity, such as population growth and land use, are some of the major factors causing environmental changes in the mountains (Slaymaker, 2010). Mountainous regions have also been referred to as water towers (Shrestha, 2005) and possibly as much as 80% of running freshwater on the planet originates in mountain areas (Viviroli *et al.,* 2003). The Himalaya (Bhutan, Nepal, northern Afghanistan, northern India, northern Pakistan and the Tibetan Plateau) and the Andes (Bolivia, northern Chile, Ecuador, and Peru) are the highest major mountain ranges in the world (Huddleston *et al.,* 2003).

1.2 Himalayan mountains

One of the most climate change-affected components of the earth is glaciers, and satellite data shows that global snow cover and ice extent have decreased by 10% since 1960s (Walther *et al.*, 2002). In particular, the Himalayas are already experiencing the impacts of such changes (Beniston, 2003; Xu *et al.*, 2009). Globalization and population growth are other two drivers for the recent changes in the Himalayas (Schild & Banskota, 2008) apart from climate change. Nevertheless, it is still complicated to differentiate between the changes in the mountains caused due to human activities and those caused without human influence (Marston, 2008; Slaymaker, 2010).

The Himalayas is a vast mountain system covering a length of two thousand four hundred kilometers and an area of about seven million square kilometers (Snedden, 2006; Singh *et al.,* 2008; Xu *et al.,* 2009). Himalaya means “house of the snow” and the Himalayan Mountains are the highest and the most massive on earth and are home to over 100 million people, some of whom live at altitudes of over 5,000m (Shrestha, 2005). Three great South Asian river systems, the Indus, Ganges, and Brahmaputra, and some rivers in China including the Yangtze, Mekong, and Xunjiang, have their source in the Himalayas (Viviroli *et al.,* 2003). The Himalayas generally attract people from many parts of the world because of their remoteness and inspiring beauty. Therefore, the tourism industry is thriving as a lucrative business and sometimes the Himalaya is also called the “natural infrastructure” of a mountainous country like Nepal (MacLellan *et al.,* 2000:173).

There is serious ecological deterioration in the Himalayas, and most mountain areas are experiencing environmental degradation. This kind of natural resource depletion in mountains is being driven by numerous factors. These mountainous areas are highly affected by deforestation, over-grazing, cultivation of marginal soils, management systems, and mismanaged tourism; all of which causes rapid loss of habitat and biological diversity (Beniston, 2003; Lambin & Geist, 2006; Snedden, 2006; Becker *et al.,* 2007; Byers, 2009). Because of the rapid change in elevation within a small range, mountains represent different ecological regions within a relatively short horizontal distance while supporting a diverse flora and fauna. These ecosystems can support various endemic species because of their isolated ecological niches (Beniston, 2003). The sharp increase in the elevation in the mountains is advantageous for studying climate change and its impacts on biodiversity and local people because of various scientific and socioeconomic factors (Korner, 2000; Becker & Bugmann, 2001; Bugmann *et al.*, 2007). As such, these areas are appealing for studies on the global environment, land use, and climate change (Zhao *et al.,* 2006).

1.3 Impacts on the Nepal Himalayas

The Federal Democratic Republic of Nepal is a land locked country surrounded by the Tibetan Autonomous region of the People's Republic of China to the north and Republic of India to the south, west and east. Within an area of 147,181 square kilometers, Nepal consists of snowcapped mountains towards the north, a lower elevation mountain region in the central part of the country, and the flat Terai towards south. It is a popular destination among the visitors around the world for adventure, cultural opportunities and ecotourism (Musa *et al.*, 2004). Nepal is one of the most well-known developing countries with nature-based tourism, especially in mountainous protected areas (Chape *et al.*, 2003) – possible because more than three quarters of the country is occupied by mountainous landscape. Deforestation is occurring in the tourist areas of Nepal because small-scale teahouses and guesthouses have a great demand of firewood for tourists (Buckley, 2001).

Protected areas in Nepal generally are inhabited; therefore it is almost impossible to manage the park without involving local people (Gurung & DeCoursey, 1994). Though local people improve their livelihoods through tourism, mismanaged tourism is putting pressure on forestlands - resulting in forest thinning, degradation, and ultimately the depletion of resources at different elevations in the alpine ecosystem (Byers, 2005; Gulia, 2007; Salerno *et al.*, 2010). Some of the environmental impacts caused by tourists trekking include vegetation and soil loss, creation of informal trails, and littering (Nepal, 2003). Therefore, the relative contribution of disaggregated impact groups (lodges, porters, yak herders, yaks and expeditions) is an important factor in understanding such degradation. It is obvious that mountain people, like Sherpas, are aware of what treasures are being lost when their fragile mountain environment is damaged, as they have been residing in the area for hundreds of years now.

1.4 Research objectives

The Nepal Himalayas, such as Sagarmatha National Park, attract different people for their natural beauty, which includes the highest peak on Earth: Mount Everest. However, increasing anthropogenic activities for tourism, coupled with the impacts of climate change, are making these already fragile mountains more fragile. In this context, clearly lacking is a broader understanding of the ecological factors, socio-economic factors, and park management system that cause land use/cover change through time in Mount Everest landscapes. This study aims to identify causes behind entire landscape failures and biodegradation in the Himalayan-protected area of Nepal (Sagarmatha National Park). This UNESCO World Heritage Site covers an area of 1,144 square kilometers in the high Himalayas. Integration of spatial and social data can provide possible causal factors, such as management failures and tourism and climate change, to explain landscape and vegetation change through time. Such changes are interconnected and, when aggregated globally, local changes in land use/cover may significantly affect the entire planet. As an *a priori* assumption, recent changes in the Himalayas have been negative and include glacial melting, GLOFs (Glacial Lake Outburst Floods) engulfing settlements, and soil and biodiversity loss.

A working hypothesis for this research is that climate change and local human activities are the causal factors for negative impacts on the Himalayas regarding livelihood in recent years. The purpose of this study is to identify and analyze patterns of land cover/land use change through time within the Everest region of the Central Himalayas and to determine how the management system and anthropogenic activities are affecting conservation patterns of the protected area in the context of climate change. A review of literature and data gathered during fieldwork, such as ground control points and local people's perception, provides the basis to characterize the diversity of land-use/cover change, in terms of spatial vegetation structure, management practices, and their environmental and socio-economic impacts in the Himalayan region.

CHAPTER 2: RESEARCH BACKGROUND

2.1 Climate change and its impacts on the mountains

Global warming and climate change have become dominant themes recently because impacts are being observed in many parts of the world. International concerns about climate change and global warming started several decades ago and concerns about the consequences have been growing since the 1980s. However, the modern concept of climate change can be traced to 1824, when theories about the greenhouse effect were offered by Jean Baptiste Fourier (Handel & Risbey, 1992; Fankhauser, 1995). Later in 1896, a quantitative theory of climate change driven by variations in carbon dioxide was published by Svante Arrhenius to explain the past occurrence of large climate changes. He was the first to predict that anthropogenic sources of carbon dioxide might lead to planetary warming (Crawford, 1997). The susceptibility of climate systems to small changes was implied by the Italian scientist Cesare Emiliani in 1966, and American climatologist William Sellers in 1967 found fossil fuel burning as one of the causes of the Earth's warming (Philander, 2008).

Although the impacts of climate change were noticed in the nineteenth century, global concern increased after the First Earth Day celebration in 1970. By 1977 there was scientific argument about major climatic risk in the next century, albeit there were doubts on cooling versus warming phenomena (Philander, 2008). The issue received global attention at the First World Climate Conference in 1979 (Gupta, 2010). Climate change more widely became a matter of international concern after the Intergovernmental Panel on Climate Change (IPCC) formed in 1988 under the auspices of the World Meteorological Organization (WMO) and the United Nations Environment Programme

(UNEP) (Agrawala, 1998). As a continuation of global concern about the consequences of climate change, several conferences were organized after that. In 2009, the United Nations Framework Convention on Climate Change held in Copenhagen ratified resolutions on different issues resulting from climate change including carbon emission, sea level rise, and melting of glaciers in the Himalayas (Gupta, 2010; Katz, 2010).

Climate change is a complex question for researchers and they have been conducting wide-ranging studies on its causes and effects. Kates *et al.* (1985) explained different scenarios including climate and society interactions, biophysical impacts, and social and economic impacts and adjustments, while analyzing climate impact analysis in the global context. Oerlemans (1986) identified glaciers as a good indicator of climate change by using a model of glacier dynamics to show that glaciers are more sensitive to atmospheric radiation than temperature and they are, in almost all cases, connected with mountains. Although mountains differ considerably from one region to another, they have one common feature: topographic complexity. As mountains in many parts of the world are susceptible to the impacts of a rapidly changing climate, and provide interesting locations for the early detection of climatic change, there is a global concern for their vulnerability. In 1998, as an example of an increase in global concern regarding mountains, the United Nations declared 2002 the International Year of Mountains, which drew attention to mountain regions and their fragile ecosystems (Odermatt, 2004).

Several studies (such as Price, 1998; Funnel & Parish, 2001; Benitson, 2003) have significantly focused on climate change impacts in mountain regions. Similarly, Beniston (2005) focused on historical observation and different aspects of the impacts of climate change on mountains in a global context. Asian mountain systems and adjacent basins in the Himalayas were studied by Bohner and Lehmkuhl (2005) to compare environmental changes through time. Moreover, Marston (2008) put forward a challenge for researchers to differentiate between environmental changes due to and without human influence in the Himalayas. Therefore, mountain geography is a prospective research platform because of the transcendent significance of mountains to global land and life.

2.2 Tourism and human impacts on mountains

As the Himalayas are extremely sensitive to global climate change, many researchers have focused their attention on the impact of climate change and anthropogenic activities. A rapid increase in the impact of climate change on glaciers has a direct impact on water, biodiversity, and livelihoods in the Himalayan countries, including India, Nepal, and China (Weidinger, 2006; Xu *et al.*, 2009). The Himalayas, on the other hand, are famous for beauty, inspiration, sacred significance, and abundant recreational opportunities; and provide a great contribution to the tourism industry in mountain-dominated countries (Marston, 2008). There is a thriving tourism industry in Nepal that improves people's livelihood through sustainable economic development initiatives and environmental conservation (Nepal & Chipeniuk, 2005). However, this industry has had a negative impact on the local ecosystem and environment because of the increase in the demand of forest products and other natural resources (Pawson *et al.*, 1984).

The impacts of human-disturbance and climate change on the mountains are not necessarily negative in all cases. Extensively grazed and human-impacted alpine meadows have a high diversity of plant species compared to unused and undisturbed areas (Niedrist *et al.*, 2009). Traditional land use management in the mountains can be useful to mitigate other changes. Also, the effects of climate change are somewhat balanced by traditional land use that preserve species diversity and ecosystems (Theurillat & Guisan, 2001). Some tree species can better withstand climate change impacts in the mountains, and a changed environment will expand their habitat (Vetaas, 2002).

The impacts of changing environments and increasing human activities on Nepal's mountain landscape have been studied by several researchers. Byers (1986, 1987, 1996, 1997) focused on Nepal's mountains, especially the Everest region, to better understand land-use and land-cover change through time, along with the factors responsible for that change, by using repeated photography and multiple observations. Perception plays an important role in defining impacts in the Everest region according to Byers and Banskota (1992). The demand on limited natural resources has increased with the growing number of tourists as early as in 1970s (Pawson *et al.*, 1984). Overharvesting of fragile alpine shrubs and plants for expedition and tourist lodge fuel, overgrazing, accelerated erosion, and uncontrolled lodge building are some of the major human impacts causing landscape change in the alpine zones (Byers, 2005).

Mountaineering and tourism have had a beneficial impact on the local economy for the 6000 people living in the park, but conversely a large negative impact on local ecology (Daconto & Sherpa, 2010). In terms of the economic benefits from the tourism, the villagers who live farther removed from the tourist routes are left behind (Nepal, 2000). As Byers (2009) found by comparing the impact of tourism in two different countries, Nepal and Peru, one of the significant causes for alpine ecosystem degradation is poorly managed adventure tourism. The chain resorts operated by other people than the

Sherpas are growing in this area and the number of people from outside is increasing as migrant workers and settlers are increasing (Daconto & Sherpa, 2010), and this can alter the Park's management systems.

An increase in the influx of tourists to fragile Himalayan landscapes is creating a conflict between maintaining a healthy environment and local economic development (Nepal, 2000). In spite of the economic benefit to the local Sherpas, tourism development had created a detrimental impact on forests and alpine vegetation because of increased demand on firewood for camping groups and hotels and the growth in construction of hotels to provide better facilities for tourists (Stevens, 2003). Climate change and the number of tourists are considered to be uncontrollable factors whereas the effectiveness of management systems is controllable (Daconto & Sherpa, 2010). There is certainly a need of proper management for the sustainable tourism in this UNESCO (United Nations Educational, Scientific and Cultural Organization) World Heritage Site (Musa *et al.*, 2004).

2.3 Land use and land cover change

Remote sensing techniques were combined with Geographic Information Systems (GIS) to analyze Landsat images to examine temporal land cover changes (see Cohen & Goward, 2004). Remote sensing techniques have been extensively used to study land cover changes through time and to assess patterns of change, to integrate environmental with social change, and to identify the risk of environmental deterioration (Sader *et al.*, 1994; Millette *et al.*, 1995; Casimir & Rao, l998; Rasmussen *et al.*, 1999). Land use and land cover analysis is one of the most widely used techniques to study environmental changes and their impacts. For such purposes, remote sensing images taken at the same season over certain intervals is preferable for research using land use/cover classification including vegetation differentiation for the mountains, (examples include Reid *et al.*, 2000; Giri *et al.*, 2003; Wilson, 2006; Bhattarai & Conway 2008; Bolch *et al.*, 2008; Kral, 2009). Moreover, repeated photography can also serve as an effective method to study historical changes in the landscape (Moseley, 2006).

Landsat MSS and TM images are useful to study land cover change in mountainous areas in spite of complex physiography and shadow effects (Gautam *et al.*, 2003). Nevertheless, it is important to cross-check their reliability when using satellite images to study such changes in the high mountains (Gautam & Wanatabe, 2004). Koirala (2010) has used remotely sensed images to depict the impacts of land cover changes on the soil erosion in the mountainous region of Nepal. Due to the lack of historic maps and aerial photos, it can be challenging to validate such data while studying remote areas in the developing countries (Griscom *et al.*, 2010). Nevertheless, several researchers have focused on the Himalayas to study land cover changes in the Nepal Himalayas as a consequence of anthropogenic and environmental factors (some examples include Byers, 1986; Virgo & Subba, 1994; Thapa & Weber, 1995; Thapa, 1996; Schweik *et al.*, 1997; Jackson *et al.*, 1998; Gautam *et al.*, 2003; Bhattarai & Conway, 2008).

Classification methods using Geographic Information System (GIS) and remote sensing techniques help interpret historic changes (Uddin & Gurung, 2010). Lu and Weng (2007) have detailed various problems with classification methods while analyzing remote sensing imagery and suggested that complexity of the landscape is one of the most challenging factors. Normalized Difference Vegetation Index (NDVI) is an effective technique for land cover change detection when analyzing repetitive satellite images (Lunetta *et al.*, 2006). An NDVI is based on the different nature of reflectances by different land cover types in visible and near infrared region of electromagnetic spectrum. An NDVI can be helpful for determining factors such as precipitation associated with land cover changes (Mingjun *et al.,* 2007). In addition, remote sensing techniques can also serve as a supplement for sociological studies (Jinag, 2003). These techniques are generally considered quantitative, but they are preferably supplemented by qualitative methods such as interviews with local inhabitants (Behrens *et al.,* 1994). Remotely sensed images are useful for detection of changes and can be combined with socio-spatial data obtained from ethnographic methods (Sussman *et al.,* 1994; McCracken *et al.,* 1999). In other words, field interviews can help to understand community land and resource use practices and land use histories (Thongmanivong & Fujita, 2006).

CHAPTER 3: RESEARCH SYNOPSIS

This study is an examination of the impacts from developing tourism, park management systems, and climate change on local livelihoods within Sagarmatha National Park, a Himalayan protected area of Nepal (Figure 1). In the context of rapidly growing tourism and global warming impacts, this study aims to measure the change in land cover types over time within the spatial extent of this park. Like other Himalayan mountains, the park is prone to environmental degradation because glacial retreat and increasing unmanaged tourism have serious, often irreversible, impacts on this fragile mountain ecosystem. For more than five centuries, this area has been inhabited by the Sherpa ethnic group and they understand the recent changes and impacts. This study uses an integrative methodology by combining spatial data analysis with sociological information to explain trends in land cover changes and possible causes.

Sagarmatha National Park is a UNESCO World Heritage Site because of several peaks; including Mount Everest and its unique mountain ecosystem. Studies on land use and land cover change in mountainous regions provided strong theoretical and methodological support for this analysis in Nepal Himalayas. The use of ethnographic knowledge gathered by interviewing local inhabitants provided the information needed to help explain the spatial data analysis. This study can provide significant guidance for the formulation of better management practices in the National Park.

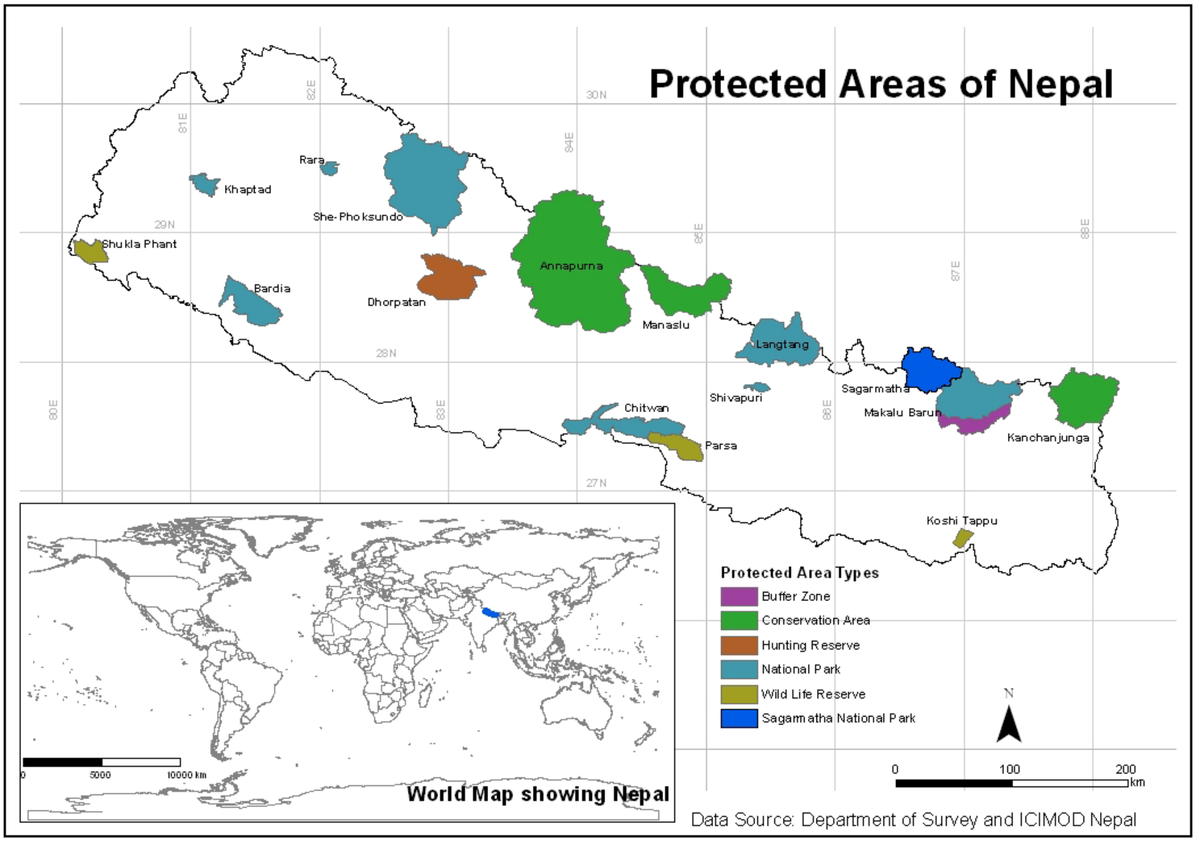

Figure 1. Map of Nepal with Protected Areas

This study used two types of classification systems while analyzing remote sensing images. These images included 1972, 1975, and 1979 MSS images and 1992, 1999, 2002, 2005, and 2009 TM images. The first method uses five elevation classes based upon a Digital Elevation Model (DEM): below 3000m, 3000-4000m, 4000-5000m, 5000-6000m, and above 6000m (Figure 2). Eight classes derived from the International Center for Mountain Research and Development (ICIMOD) land cover data were used as the second classification method (Figure 3, 4 and 5). These classes included Agriculture/Houses, Broad Leaf, Mixed Forest, Needle Forest, Rock/Soil, Shrub/Grass, Snow/Glacier, and Glacial Lake. The land cover classes were further verified using 518 Ground Control Points (GCPs) collected during September 2009 and March 2010.

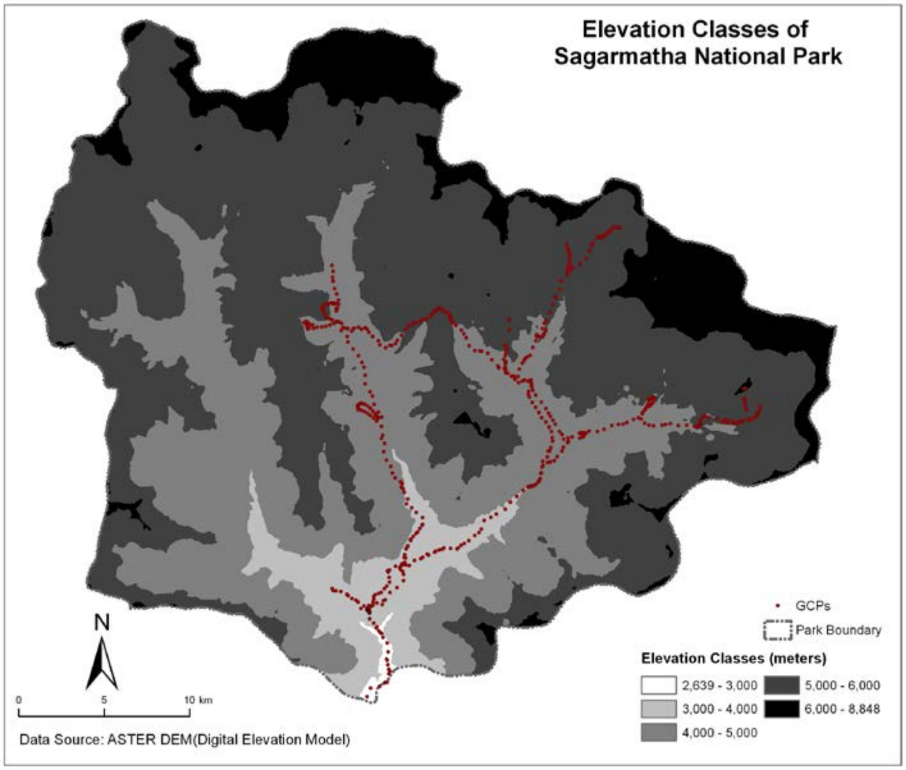

Figure 2. Sagarmatha National Park Elevation Classes

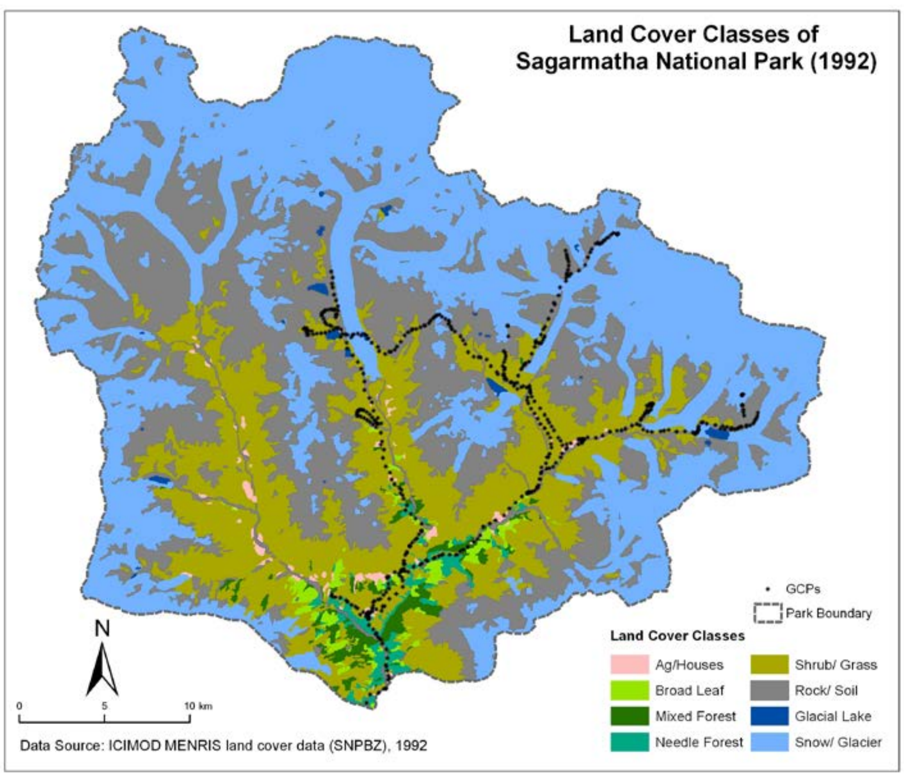

Figure 3. Sagarmatha National Park Land Cover Classes (1992)

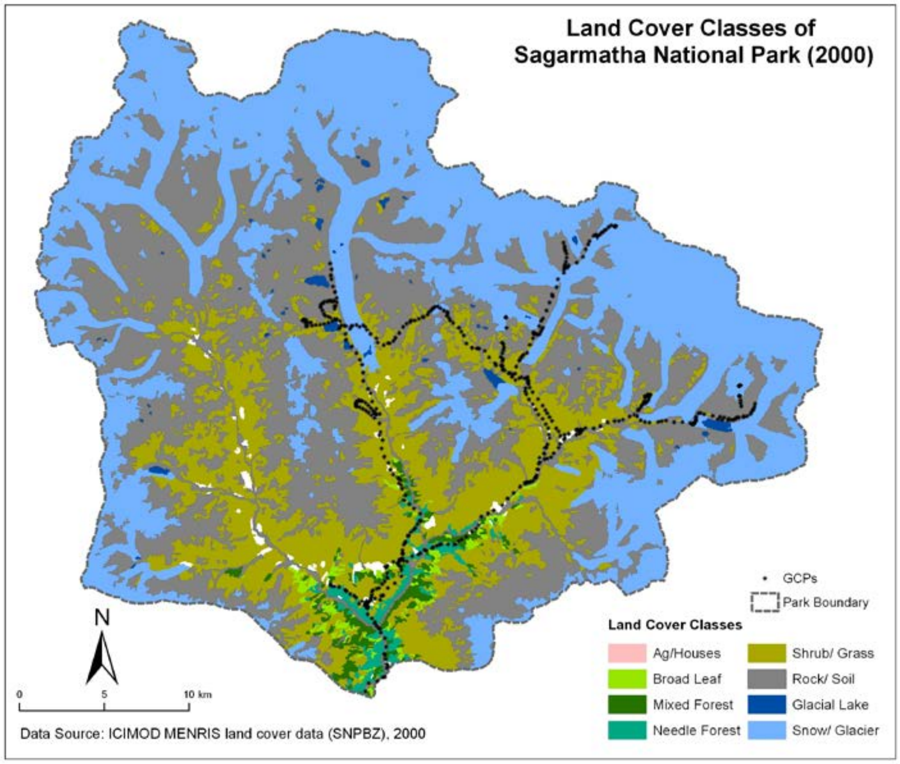

Figure 4. Sagarmatha National Park Land Cover Classes (2000)

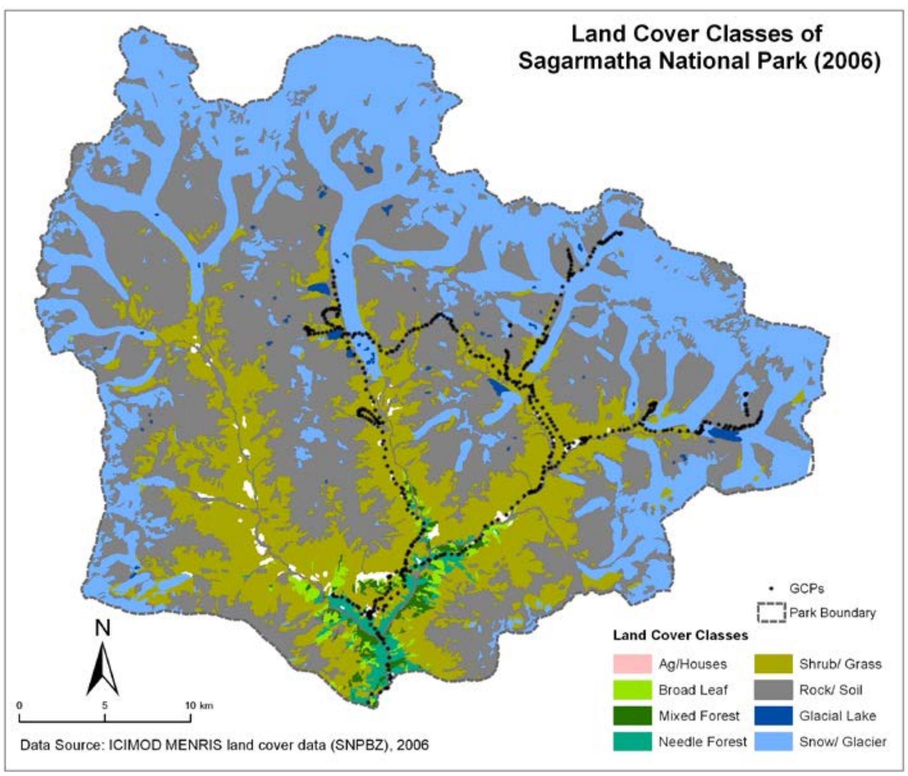

Figure 5. Sagarmatha National Park Land Cover Classes (2006)

In addition, these GCPs were used to analyze disturbance factors in the region as detailed information associated with each ground point was collected during the field visit (Appendix II). The interviews were conducted to document local people's observations on land cover and other changes over time and the underlying causes. The interviewees included major stakeholders of the National Park: local permanent residents, tenants, lodge owners and runners, workers, tourist guides, herders, travelers, and park officers. Moreover, eight photographs were taken at each ground control points for visual documentation of conditions in the park. Some of the pictures are provided in Appendix III.

The reflective contrast of vegetation in the the Near Infrared (NIR) and visible red wavelengths is the foundation for the creation of vegetation indices. A Normalized Difference Vegetation Index (NDVI) is calculated using spectral enhancement technique in ERDAS Imagine software and this was preformed for each of the classes for all the MSS and TM images. NDVI is the difference between reflectance at NIR and Red normalized by the sum: (NIR-Red) / (NIR+Red). NDVI values range from -1 to +1, in which positive values representing vegetated areas whereas negative values indicate non-vegetated areas such as rock, soil, snow, ice and water. The change was measured using intersection overlay technique in ArcGIS software, which distinguishes the areas common on both (unchanged) and changed areas between the two data files.

3.1 Results summary

The trend of average NDVI values for the whole park area shows an increase of the values for the period of 1972-2009 (Figure 4). However, the data from local stakeholder interviews and ground control points suggest a decrease in forested areas with the increase in the number of tourists. However, inactive park management systems due to the Maoist conflict in the late 1990s and early 2000s led to the far greater exploitation of natural resources. After the conflict ended, the resurrection of the park management along with some of the Community Based Organizations (CBOs) helped to restore some of the destructed areas in the mid and late 2000s. This trend corresponds to the number of tourists visiting the National Park, as tourists become a proxy for active Park management. As the major source of economy is tourism, this fluctuation makes a huge difference in the local livelihood and the local people were very concerned about this variation.

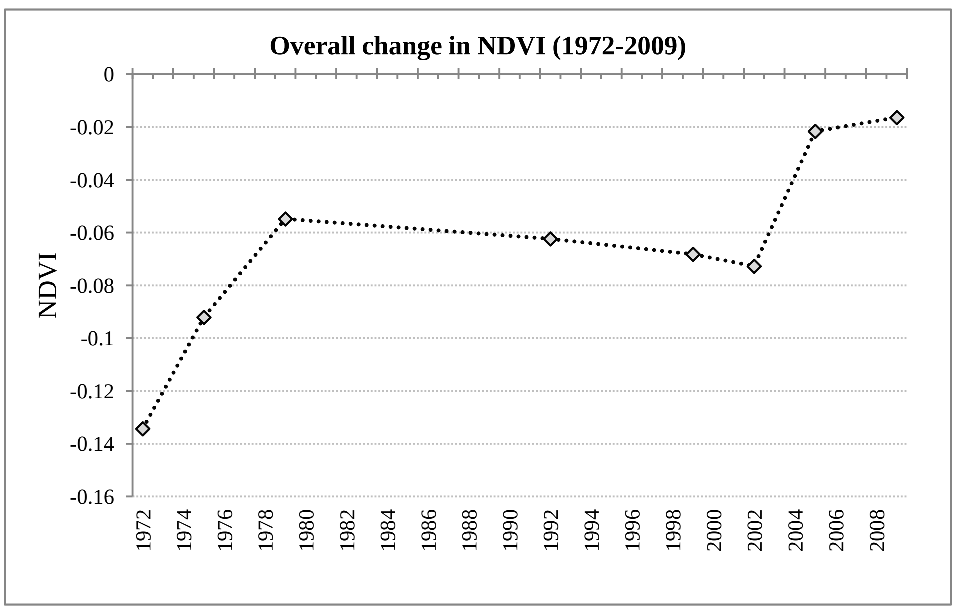

Figure 6. Average NDVI trend for the entire Sagarmatha N.P. (1972-2009)

This trend can imply either an increase of vegetated areas or the loss of snow or ice exposing more rocks and bare soil – both of which are consistent with climate change impacts. Land cover change analysis using intersection overlay technique in ArcGIS software suggests the major change is a transformation of ice, shrub, and grass covered areas to bare rock and soil (Figure 7).

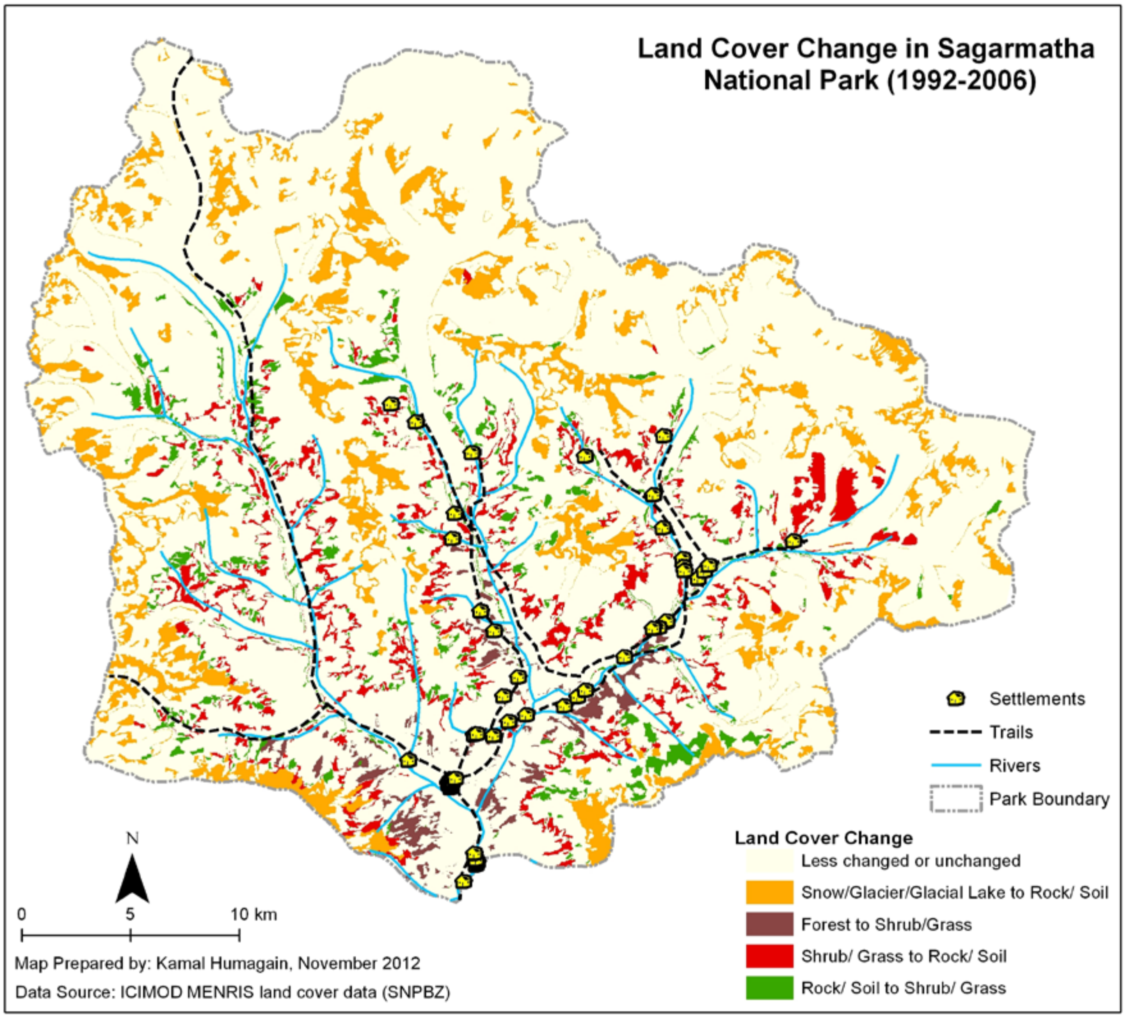

Figure 7. Land cover change (1992-2006)

A land cover change matrix shows the relative changes for land cover types (Table 1). The areas covered with ice and snow declined by 23.85% - most of which converted to bare rock and soil. A significant proportion (20.88%) of the shrub and grass areas has been converted to rock and soil. Broadleaved and mixed forests have been clearcut and transformed into shrub and grass by more than 40%. Almost 20% of the needle forest has been transformed into shrub and grass. The transition between 1992 and 2006 has been detailed in the attached manuscript (Appendix I). Forests and other vegetated areas have been lost continuously in 1990s and 2000s, while the change of ice covered areas to bare rock and soil have been accelerated in 2000s. Shrubs and grass tend to grow in the newly constructed habitats if adequate soil is present and some of the areas have been recovered with vegetation.

Table 1: Relative (%) land cover change (1992-2006)

LCC	Ag/ Houses	Broad Leaf	Mixed Forest	Needle Forest	Shrub/ Grass	Rock/ Soil	Glacial Lake	Snow/ Glacier
Ag/ Houses	79.94	1.69	0.84	1.58	12.06	3.57	0.18	0.14
Broad Leaf	0.31	37.35	**10.33**	6.65	**42.70**	2.66	0	0
Mixed Forest	0.35	9.31	31.23	4.95	**44.55**	9.62	0	0
Needle Forest	0.16	6.09	4.87	67.17	**19.43**	2.28	0	0
Shrub/ Grass	0.23	0.95	0.51	1.17	75.93	**20.88**	0.04	0.28
Rock/ Soil	0.12	0.12	0.07	0.11	**8.96**	88.52	0.26	1.85
Glacial Lake	0	0	0	0	1.72	6.21	79.68	12.39
Snow/ Glacier	0	0	0	0	1.78	**23.85**	0.33	73.97

Interviews provided a qualitative hint of changes, whereas an analysis based on satellite images during the 1990s and 2000s display significant quantitative results regarding the changes occurring in this fragile landscape of the Himalayas. Therefore the changes in the park and the underlying causes are a prime matter of local concern. Based on the local people’s perception, the ineffectiveness of park management system and high demand of natural resources due to increasing number of tourists are the major causes for changes in local ecosystem. Locals have experienced rapidness in glacial retreat, lake size expansion, and glacial lake outburst flood events in the past few decades. However, they are not aware of possible causal factors such as global warming because of the lack of environmental education. While global warming is uncontrollable at the local level, better management practices may help to rehabilitate degraded areas in the park and to conserve this unique high mountain ecosystem.

3.2 Future research

Future research is possible with more high-resolution satellite images and a shorter temporal interval to better analyze the changes, but much depends on image availability and cloud cover. A classification based on past images would help to observe changes given a longer data period and with more regular intervals from 1970s to the present date. Multiple field visits and more representative ground control points may also help to categorize land cover classes and to measure changes more accurately. In spite of its cost and time intensive nature, these methods may produce better analysis of environmental changes through time. Moreover, this type of research may be replicated in other national parks or protected areas of Nepal to examine the similarity and differences between the patterns of land cover changes.

APPENDIX I: Manuscript: Using satellite imagery to study land cover change in Sagarmatha National Park, Nepal

To be Submitted to *Remote Sensing of the Environment*

USING SATELLITE IMAGERY TO STUDY LAND COVER CHANGE IN SAGARMATHA NATIONAL PARK, NEPAL

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Abstract

Sagarmatha National Park, a UNESCO World Heritage Site, is one of the fastest growing tourist destinations in Nepal and is the location of Mt. Everest – the highest mountain in the world. With more than 70% of the area covered by ice, rock, and bare soil, this mountain ecosystem is vulnerable to global and local changes. This paper presents an integrated methodology for examining this process by combining spatial data with sociological information gathered from semi-structured informal interviews. Digital Elevation Model (DEM) and land cover data from International Centre for Integrated Mountain Development (ICIMOD) was used to create classes for Multispectral Scanner (MSS) and Thematic Mapper (TM) satellite images by incorporating ground data. Normalized Difference Vegetation Index (NDVI) data was calculated to observe the changes during1972-2009 for elevation classes and 1992-2009 for land cover classes. The results from both the elevation and land cover classes NDVI trend analysis indicate the loss of ice-covered areas and an increase in the glacial lakes, bare rock, and soil. The land cover change analysis shows a conversion of 23.85% of ice-covered and 20.88% of vegetated areas (shrub and grass) to bare rock and soil for the period of 1992-2006. The melting of glacier has accelerated in the 2000s than in 1990s and the glacial lakes have expanded by 43.67%. The park has significantly lost forested areas to shrub and grass. These areas spatially shifted towards higher elevation in 2000s than in 1990s. Most local residents believe increasing tourism, ineffective park management, and consequent

pressure on natural resources are important local factors causing such changes. Human influence coupled with climate change may explain the changes in higher elevation whereas anthropogenic activities are solely responsible in the lower areas. Given the global factors are uncontrollable, better management practices may help to restore the deteriorated mountain ecosystem and to ameliorate the problem of mismanaged tourism.

1. Introduction

Developing nations are experiencing rapid land cover change for a variety of reasons. Increasing population, poverty, and poor economic development are some of the factors for these changes in most Asian countries, and these changes eventually put pressure on natural resources (Seto *et al.*, 2002; Giri *et al.*, 2003; Kelarestaghi & Jeloudar, 2011). Land cover and land use change (LCLUC) analysis based on data received from spaceborne sensors is an important component of environmental research (Brandt & Townsend, 2006; Cingolani *et al*., 2004; Sharma and Xu, 2007). The methods using these data are more convenient as compared to field intensive methods for the areas with complex physiography to study the changes occurring due to socioeconomic and environmental factors (Eiumnoh & Shrestha, 2000; Roberts *et al*., 2003; Zhu, 1997). Satellite images have been used in land cover analysis in remote, less accessible and high elevation mountainous areas including Nepal (Millette, 1995; Zomer *et al.,* 2002).

Remote sensing data is gathered based on the reflectance of earth surface in the electromagnetic spectrum. Because of the variation in reflectance by different land cover types, measurements from two or more spectral bands are used to calculate vegetation indices (Jackson & Huete, 1991), among which a Normalized Difference Vegetation Index (NDVI) is one of the widely used (Tucker *et al.*, 1986; Song & Zhang, 2010). NDVI differencing techniques are among the best means for vegetation change detection because of the different nature of reflectance of plant greenness in visible red and infrared wavelength (Lyon *et al.*, 1998; Lu *et al.*, 2003). This index has been empirically correlated to different variables such as biomass, vegetation cover, leaf area index, productivity, and carbon in the standing biomass (Tucker, 1979; Asrar *et al*., 1985;

Sellers, 1985; Tucker *et al.*, 1986; Verstraete & Pinty, 1991; Song & Zhang, 2010).

Using data based on the reflectance of earth surface has been effective in many studies because of the repeated acquisition and availability in digital format (Lu *et al.*, 2003). One of the important applications of remotely sensed data is quantitative representation of the area of interest by classifying it into land cover classes and its application in local, regional, and global scales (Foody, 2005). On the other hand, the accuracy of the remote sensing imagery for the mountainous areas can be affected by rough terrain, steep slopes, deep valleys, shadows of high mountains, and discrepancy in vegetation cover (Yacouba *et al.*, 2009) and these kind of data alone may not be sufficient for the land cover classification (Arora & Mathur, 2001). The efficacy of satellite image use can be improved by incorporating detailed field studies data (Moran *et al.*, 1994).

A narrative perspective of local resident perceptions can help develop an understanding of land cover change and historic natural events (Bruzzone, 1997; Fox & Vogler, 2005). Short, informal interviews with the local residents and stakeholders are crucial for understanding past land cover changes that might not be reflected in satellite images (Serneels *et al.*, 2001; Giri *et al.*, 2003). Additionally, spatial analysis may miss the underlying factors for such changes at household level unless interview data is incorporated (McCracken *et al.*, 1999). Therefore, information from local inhabitants is an important aspect of land cover studies to better explain the local causal factors - in spite of the cost-intensive nature of collecting this data (Thomson *et al.*, 2002; Gellrich *et al.*, 2008). Moreover, spatial data integrated with information from social survey and socioeconomic data are useful to help answer human-environment interaction questions

(Veldkamp & Lambin, 2001; Walsh *et al.*, 2001).

There is serious ecological deterioration occurring in the Himalayas, and most mountain people have experienced environmental degradation locally. This kind of natural resources depletion in mountains is being driven by numerous factors including deforestation, over-grazing, cultivation of marginal soils, traditional management systems, and mismanaged tourism because mountain ecosystems are susceptible to soil erosion, landslides and rapid loss of habitat and genetic diversity (Beniston, 2003; Lambin & Geist, 2006; Snedden, 2006; Becker *et al.*, 2007; Byers, 2009). High population growth, rapid economic development and poverty are some of the other possible underlying driving forces for such changes (Giri *et al.*, 2003). Moreover, the changes in forests and other vegetated areas are mainly caused by anthropogenic activities.

The landscape of the Himalayas is a tectonically unstable, ecologically fragile, economically underdeveloped mountain ecosystem with high human influence (Byers 2005; Marston, 2008; Tiwari, 2008; Cui & Graf 2009). Sagarmatha National Park (Figure 1) is located in this fragile landscape of the high Himalayas with more than 70% of the area covered by ice, glaciers, rock outcrops, and bare soil. The park has been home to the Sherpas for more than 500 years (Sherpa & Bajracharya, 2009) and it has been through many changes during this time. Bajracharya and Uddin (2010) found a significant decrease in the forested areas, cultivated areas, glacier and snow and a substantial increase in glacial lakes, bare area, and grasslands in the SNP and buffer zone areas for the period of 1992-2006. The glacial ice reductions can lead to the expansion in the size of glacial lakes (Hegglin & Huggel, 2008). Yong *et al.* (2010) observed a continuous retreat of glaciers across the Mt. Qomolangma (Mt. Everest) and a rapid expansion of glacier lakes for a period of 1976-2006 by analyzing MSS and TM images. Increasing temperatures is one of the most important factors to cause melting of glaciers and ice in the Himalayas (Ren *et al.*, 2004).

In general, local people seeking to use and exploit natural resources do so in order to become economically more diversified, particularly in developing areas. As such, Sherpas have shifted from a trade-based to a tourism-based economy since 1970s because of the significant increase in the inflow of tourists (Basnet, 1992). The establishment of the Lukla Airport in 1964 has been inviting the people from different parts of the world to the Everest region. The total number of tourists is increasing – from 20 in 1964 (Naylor, 1970 cited by Byers, 2005), below 5,000 in 1970s, around 10,000 in 1980s, over 20,000 in 1990s (Stevens, 2003), slightly over 21,000 in mid 2000s, above 30,000 in late 2000s to over 34,000 in 2011 (MCTCA, 2012). The majority of the tourists include trekkers (mainly to Everest base camp, Gokyo Lake, and Tengboche Monastry) and Everest climbers. This soaring number of tourists has a direct impact on the mountain ecosystem and it has led to demands for more lodges, more firewood, and other forest products. This situation creates a problem for resource managers to manage the resources and to fulfill the demands from an increasing population (Mondal & Southworth, 2010). Therefore, this resource-human conflict is one of the major reasons for the inefficacy of the park management (Hijortso *et al.*, 2006).

Local people’s expectations for economic opportunities have changed due to tourism development. Hotel and lodge owners, shopkeepers, porters and guides (local and outsiders), yak herders, farmers, monks, and other workers are always expecting bigger inflow of tourists. Although increasing tourism improves the local economy, lack of proper management can have a heavy impact on the environment (Cui & Graf, 2009). Several Community Based Organizations (CBO) including buffer zone user group, Sagarmatha Pollution Control Committee (SPCC), Himalayan Trust, Khumbu Alpine Conservation Committee (KACC), and eco-club are working to better management tourism and natural resources. Nevertheless human activities to drive land changes continue to have a large impact on mountain ecosystems (Becker *et al.*, 2007). Though local people are earning money for their livelihood improvement from tourism, mismanaged tourism is putting pressure on forestlands, resulting in forest thinning, degradation, and ultimately the depletion of resources in different levels of the alpine ecosystem (Byers, 2005; Salerno *et al.*, 2010). Himalayan protected areas are going through rapid land cover changes and a high impact of tourism (Cole & Sinclair, 2002) and the Sherpas understand these impacts better than any other people. The interactions between humans, climate change, and land cover change mostly have negative impacts on vulnerable mountain ecosystems (Byers, 1987 & 1997; Stevens, 2003; Vetaas, 2002). Sagarmatha National Park (SNP) is experiencing increasing pressure from tourism and environmental changes in recent years (Nepal, 2000; Stevens, 2003; Byers, 2005).

In the context of increasing anthropogenic factors and global environmental impacts, this study examines land cover changes using spatial data and investigates the patterns of these changes in relation to physical and socioeconomic factors. There is a clear gap in the literature of studies utilizing remotely sensed data and ethnographic knowledge to analyze land cover changes in this World Heritage site (exception includes Bajracharya & Uddin, 2010). The present work applies NDVI trend analysis integrated with social data to examine historic changes in land cover. In addition, LCLUC analysis was conducted to investigate quantitatively the dynamics and changes among difference land cover types in two study periods, namely, from 1992 to 2000 and from 2000 and 2006. Analysis of spatial data derived from Landsat satellite imagery and field data, along with information on local people's perceptions, characterizes the dynamics and diversity of land cover changes and its impacts on the ecosystem.

2. Study Area

The study area is Sagarmatha National Park (27°45′-28°07′N and 86°28′-87°07′E) which is one of nineteen protected areas in Nepal and a UNESCO (United Nations Educational, Scientific and Cultural Organization) World Heritage Site (Figure 1). Within an area of 1,148 square kilometers, the elevation of the park ranges from 2,639 meters to 8,848 meters. The northern part of the park forms the international boundary with the Tibetan Autonomous Region of China. The park is largely composed of rugged terrain including gorges of the high Himalayas and several high mountain peaks including Mount Everest (Sagarmatha in Nepali). Most of the area is dominated by ice (glaciers) and rock outcrops at the higher elevations and forested areas in the lower region (Figure 1).

The park includes Namche, Khumjung, and small portion of Chaurikharka Village Development Committees (VDCs) of the Solukhumbu district. The ancestors of the Sherpas migrated from eastern Tibet and settled in the Khumbu valley about 500 years ago (Byers, 2005; Sherpa & Bajracharya, 2009) and in the past their population was slightly more than 80% of the six thousand people living within the National Park. Sherpas work as farmers, yak herders, traders, and as mountain climbers in the Himalayas

(Snedden, 2006). During the winter, most of the people living at higher altitudes move their cattle down to lower elevations, while some of them temporarily migrate to Kathmandu and other cities because of the frigid temperatures and significantly reduced tourist flow.

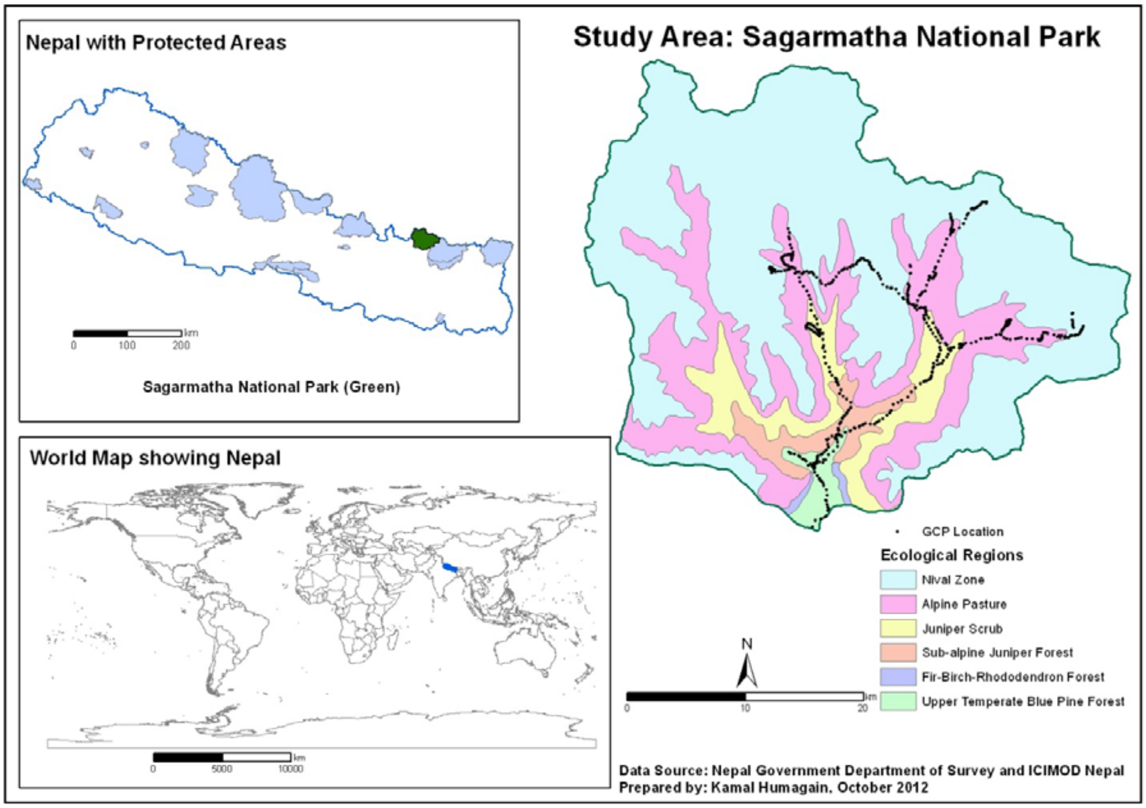


Figure 1. Study area: Sagarmatha National Park, Nepal (black dots show the location of the ground reference data collected during 2009 and 2010)

3. Data

3.1 Satellite Imagery and Other Geographic Data Layers

Multi-temporal satellite datasets from different sensors were used to assess land cover changes in the Mount Everest region. Landsat images from 1972 were used to examine historic NDVI to evaluate how the different regions within the park have changed through time. Multispectral Scanner (MSS) was used for 1970s, then Thematic

Mapper (TM) for the 1980's and beyond. Because of the need for cloud free images, a regular interval could not be used when acquiring imagery from the United States Geological Survey website (Table 1). In particular, to avoid the expected errors, image available for 1989 was discarded as it was significantly covered by the clouds. Because the Asian Monsoon occurs during the spring and summer, datasets were selected, even though less ideally, from relatively cloud-free scenes acquired during winter or late fall (Table 1). In addition, an ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) DEM (Digital Elevation Model) was also obtained from the same source.

Table 1: Landsat MSS and TM acquisition

Date	Sensor	Path	Row	Number of bands	Resolution (m)
12/14/1972 11/02/1975 01/06/1979	MSS	50	41	4	60*60
11/17/1992 11/29/1999 12/23/2002 11/05/2005 10/31/2009	TM	140	41	8	30*30
	ASTER	-	-	-	30*30

The International Center for Mountain Research and Development (ICIMOD) has created land cover datasets for Sagarmatha National Park and its buffer zone. Land cover data for 11/17/1992 (based on TM data), 10/30/2000 (based on Enhanced Thematic Mapper-ETM+) and 02/01/2006 (based on ASTER) were obtained from ICIMOD Office

Kathmandu. Apart from that, park boundary and ecological zone layers were also obtained from the same source. Other spatial data layers such as roads, country boundary and other political divisions were obtained from the Nepal Government Department of Survey.

3.2 Field Data

A total of 518 ground control points were collected during field visits in September 2009 and March 2010; which represented all the land cover types in the National Park area. The ground reference data was collected using a Geographic Positioning System (GPS) receiver (Garmin: GPSMAP 60CSx). Customized data tables were used to collect information associated with each location apart from geographic coordinates and such data included elevation, aspect, slope, vegetation cover (upper and middle canopy, and ground cover), disturbance factors (such as erosion, grazing, and fire), and other information on the locality. The information was gathered based on an approximately 30-meter diameter pixel ground coverage. Ground reference data was collected using a systematic sampling design mostly along the tourist routes in the park area, including opportunistic points for important features (landslide, settlements, and forest stand) encountered on the sampling site.

Field interviews were conducted to elicit people's perception on causes and consequences of land cover changes within the National Park. The interviews were carried out with 68 participants, including 14 females, from different villages and with various backgrounds, selected systematically for a better spatial coverage. The people were interviewed randomly within each cluster or settlement. As a tourist area, the Everest region is visited by people from myriad parts of the country, as well as by many foreigners. People interviewed were initially encountered on the trails, in the hotels, meadows, or in cowsheds. The interviews were open ended and mainly focused on changes in the landscape in recent years, park management, and different aspects of tourism. The interviews were conducted using an inverted pyramid approach, with broad questions at first to build the context, followed by topical, and then specific questions.

4. Methodology

4.1 Satellite Imagery

The downloaded satellite images (MSS, TM and ASTER DEM) were processed through several steps before the analysis could occur. Radiometric correction was performed prior to data acquisition. Layer stack operations were used to combine several layers of MSS and TM sensors to make a single image for each observation year. All bands of MSS image (MSS Visible to Infrared) were used for layer stacking in ERDAS Imagine software because they have the same pixel size (60m) whereas band 6, with a different pixel size (120m), was excluded while layer stacking TM visible to shortwave infrared (bands 1 to 5 and 7 with pixel size 30m). All these images, along with ASTER DEM and several vector data layers, were georeferenced to World Geodetic System (WGS) 1984 UTM (Universal Transverse Mercator) Zone 45N. All the projected images were clipped to the park boundary to delineate the study area. A DEM was used to create five elevation classes by recoding operation in ERDAS Imagine which resulted separate image files for each class: 2000-3000m, 3000-4000m, 4000-5000m, 5000-6000m, and above 6000m. Using these classes, each of the clipped MSS and TM images were processed in ERDAS Imagine using multiplication operator which created a total of 40 images (five elevation classes for each of the eight images).

4.2 Normalized Difference Vegetation Index (NDVI)

NDVI was calculated by using spectral enhancement technique for all the classes created for nine observation years and complete images for the whole park. Among several possible vegetation indices, Normalized Difference Vegetation Index (NDVI) uses near infrared (NIR) and visible red to calculate the ratio of the difference in reflectance to the sum of these two as follows:

$$\text{NDVI} = \frac{\text{NIR - Red}}{\text{NIR + Red}}$$

NDVI values range from −1 to +1: no chlorophyll or non-vegetated areas have values less than 0 whereas areas with healthy or high chlorophyll have values greater than 0 (Deering *et al.*, 1975 cited by Morawitz *et al.*, 2006; Jensen, 1996). NDVI values for bare soils and other such background materials are generally between -0.1 to +0.1 whereas clouds, water, snow and ice give negative values (Goward *et al*., 1986). NDVI values, in general, for dense vegetation is 0.5, sparse vegetation is 0.09, bare soil is 0.025, snow and ice is -0.046, and water is -0.257 (Holben, 1986).

4.3 Land Cover Change Analysis

Since the Landsat program started in 1972, Multispectral Scanner (MSS) and Thematic Mapper (TM) data have been efficiently used for land cover analysis (some examples include Botkin *et al.*, 1984; Toutoubalina & Rees, 1999; Stefanov, 2001; Yang & Lo, 2002; Gautam *et al.,* 2003; Zha *et al.,* 2003; Galicia & Garcia-Romero, 2007; Kumar *et al*., 2007; Bhattarai & Conway, 2008; Yong *et al.,* 2010). Land cover class (LCC) vector layers obtained from ICIMOD were used in the following sequence: LCC 1992 for 1992 image, LCC 2000 for 1999 and 2002 images, and LCC 2006 for 2005 and

2009 images. These land cover categories were reclassified to create eight classes with the definitions provided in Table 2 and eight different polygon layers were created.

Table 2: Land-cover classes in Sagarmatha National Park

Land Cover	Definition
Agriculture/Houses	Cultivated areas, built up areas, settlements
Broad Leaf	Broadleaf forest closed to open (100-40)% trees
Mixed Forest	Multi-layered mixed trees
Needle Forest	Needle-leaved closed to open (100-40)% trees
Rock/Soil	Bare Soil, gravels, stones and boulders, rock with few plants
Shrub Grass	Closed to open shrubland (thicket), meadows, grasses
Glacial Lake	Natural water bodies (standing) formed from the glacier
Snow/Glacier	Snow, moving ice

A total of 40 image files were produced by clipping each of the five TM images with these eight vector layers in ArcGIS Desktop software and NDVI was calculated for these classes in ERDAS Imagine software. These reclassified classes were further processed in ArcGIS to measure the quantitative changes in the land cover types. Intersection overlay method was applied to measure absolute and relative changes for 1992-2000, 2000-2006, and 1992-2006. Land cover change matrices were prepared and represented in separate maps to show the spatial distribution of these changes.

4.4 Field Data Processing

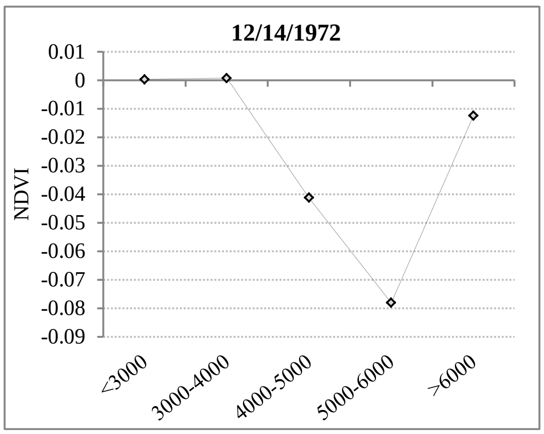
A total of 518 data points collected from Sagarmatha National Park were digitized and double-checked to minimize possible errors of missing or misplacing data. The points were further rechecked based on World Imagery using ArcGIS software for quality assurance. The data in the Microsoft® Excel table was converted into ArcGIS compatible format and processed so that the attribute data could be analyzed based on their spatial location. These points were used to validate land cover classification created by ICIMOD and to interpret the results. Satellite image classifications were field checked for the major impact regions of National Park. The field interviews conducted with residents also helped to facilitate this analysis.

The information based on interviews were categorized and then processed to make it suitable for quantitative analysis. As the interviews were subjective, a list of changes occurred in the park and the underlying causes were prepared and the percentage was calculated by recording the number of people indicating those changes and causes. The data were analyzed to determine local peoples' perceptions on land cover change, tourism, and park management along with the general information such as ethnicity, income, and profession. Several graphs and tables were generated using Microsoft® Excel software. The ground control points and the results from the interviews were used to improve the interpretation of the land cover classification.

5. Results

5.1 NDVI Elevation Classes

The majority of the park area lies within the elevation classes of 4000-5000m (31%) and 5000-6000m (52%). NDVI trends show that the 3000-4000m zone is the most productive elevation and that the 4000-5000m elevation zone is becoming much more productive after 2005 (Figure 2 a-h). This zone has quickly recovered after vegetative losses during 1992-2002 (possibly associated with an armed insurrection during that time). The least productive zone is 5000-6000m where there is essentially little or no vegetation and the land is dominated by rock and ice. NDVI values for the highest elevation zone (mostly glacier and ice) might have been influenced by the high slope of the mountains and by shadow effects; otherwise it generally has a lower NDVI than the lower elevation zones. Changes in the lower elevation are mostly caused by the anthropogenic activities.



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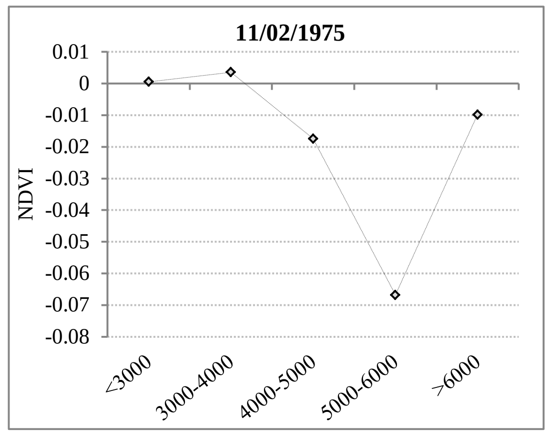

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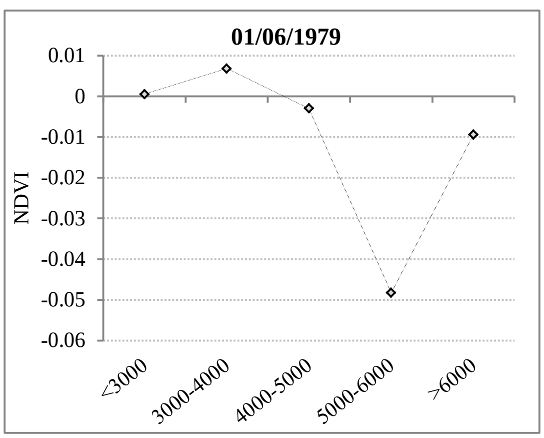

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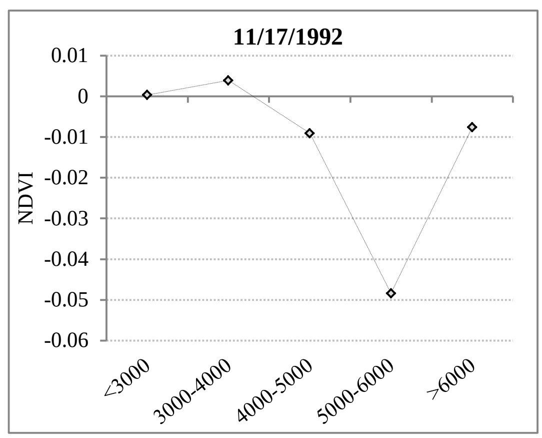

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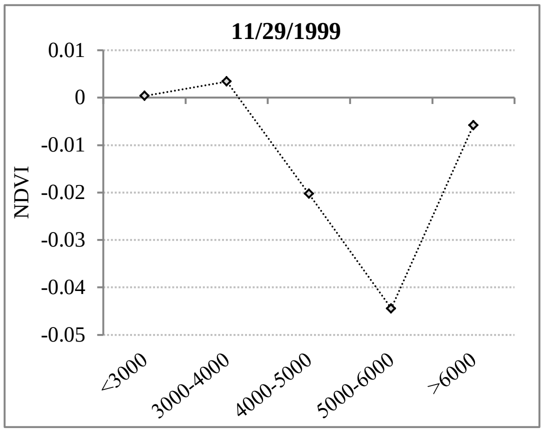

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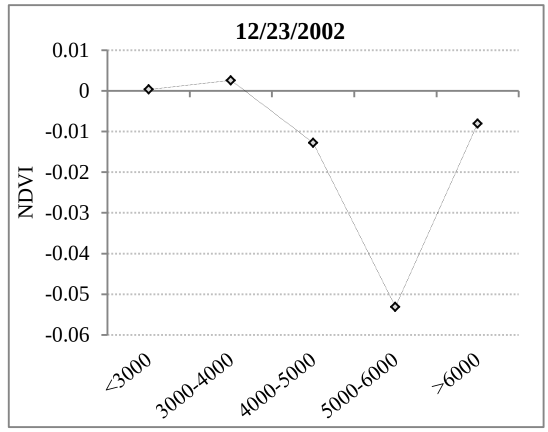

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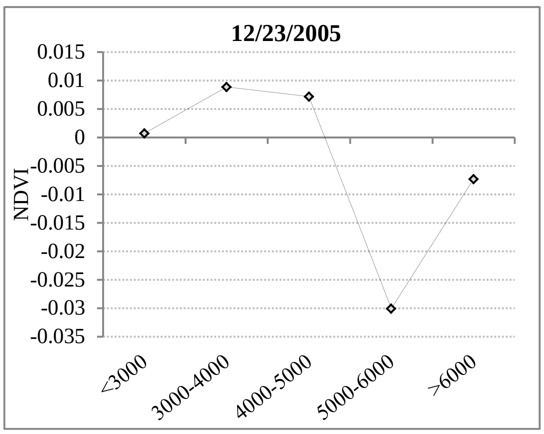

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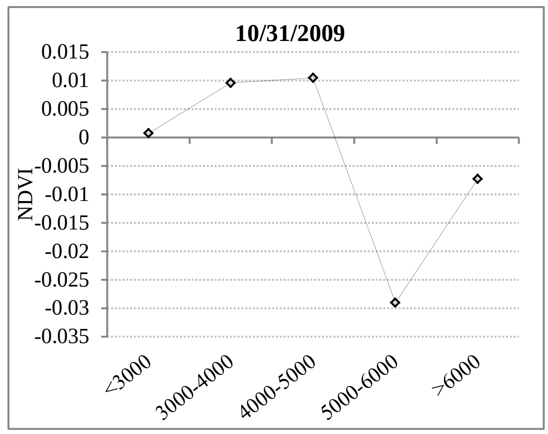


(h)

Figure 2. NDVI for elevation classes (classes in meters along x-axis): a) 1972 b) 1975) c) 1979 d) 1992 e) 1999 f) 2002 g) 2005 h) 2009

Apart from the local residents, Nepalese from outside the park are also affecting the ecosystem in this region. While Sherpas are still the most dominant ethnic group, resource management has been changing from Sherpa to non-Sherpa people. This transformation in resource usage, along with lucrative tourism, has led to deterioration in the mountain ecosystems. Grazing has decreased in more remote areas as Sherpas have changed their profession towards a tourism-based economy rather than cattle rearing. This human impact may explain the increase in NDVI in the 4000-5000m elevation zone. In search of better education and opportunities for the next generation, many Sherpas are migrating towards bigger cities such as Kathmandu. They are being replaced by Rai and Gurung people from lower parts of the district. These new immigrants do not follow traditional grazing practices, which have had a great influence on land cover in 3000-5000m elevation zone. Melting of ice and snow and exposure of rocks likely caused an increase in NDVI values for the regions above 5000m.

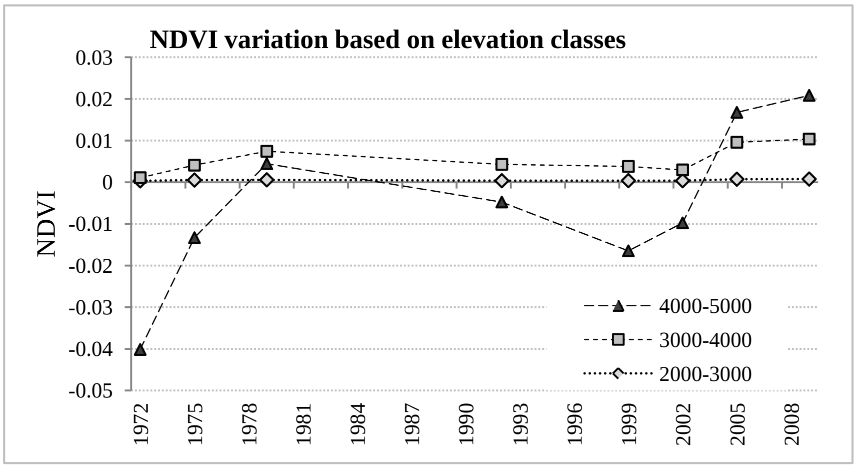


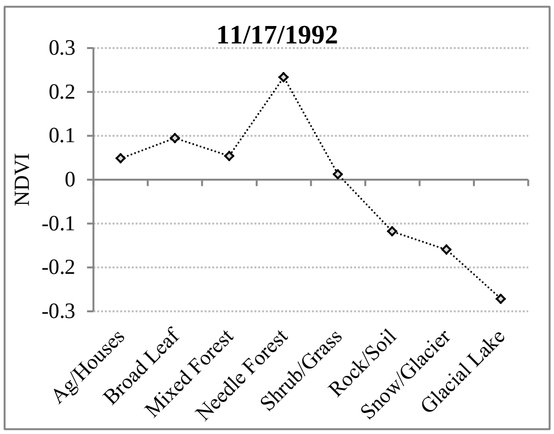
Figure 3. NDVI trend through time based on elevation classes

The combined NDVI trend line for the elevation classes below 5000m shows overall increase in NDVI except 2000-3000 (Figure 3). This lowest elevation zone in the park covers a small portion of the park and it has been heavily influenced by human activities for settlement, agriculture, and harvesting of forest products. The most productive zone is 3000-4000m, with its coniferous and broadleaf forest and some shrubs, which decreased in productivity in the late 1990s, but recovered thereafter.

5.2 NDVI Land Cover Classes

Individual NDVI graphs were prepared for the TM data after 1992 because this is based on land cover classification data by ICIMOD and the data is available for the years 1992, 2000, and 2005 (Figure 4). The graph for TM NDVI 1992 is based on the ICIMOD

1992 classes, graphs for 1999 and 2002 are based on ICIMOD 2000 classes whereas 2005 and 2009 graphs are based on ICIMOD 2006 classes. Needle forest is the most productive zone among the eight classes - with the highest NDVI – and it is followed by mixed and broadleaf forest. Glacial lakes have the lowest NDVI values because they are dominated by melted ice and water – which absorb very strongly in the NIR. After 2002, the areas with shrub and grasses have recovered quickly with positive NDVI values.



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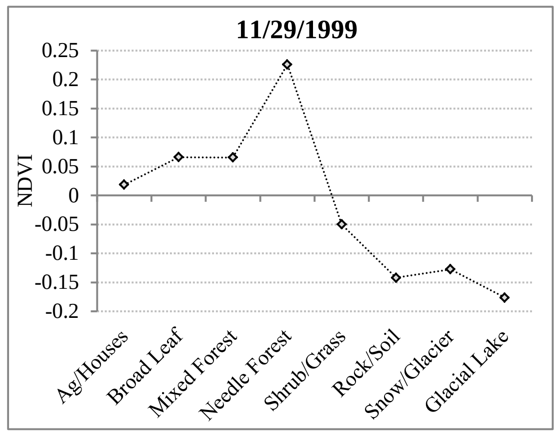

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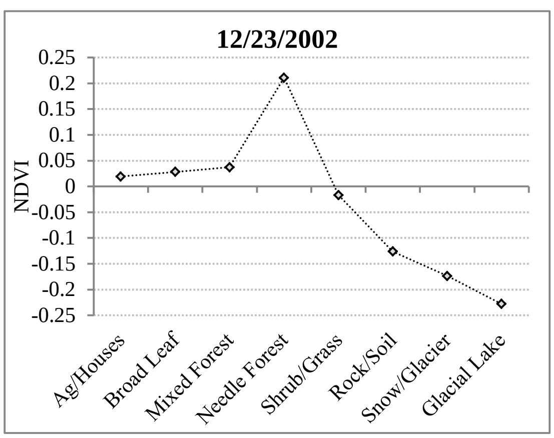

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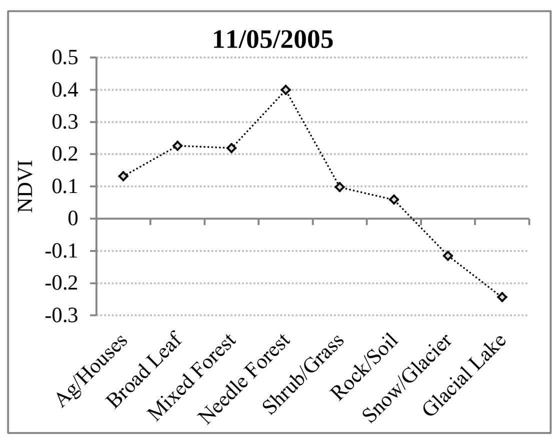

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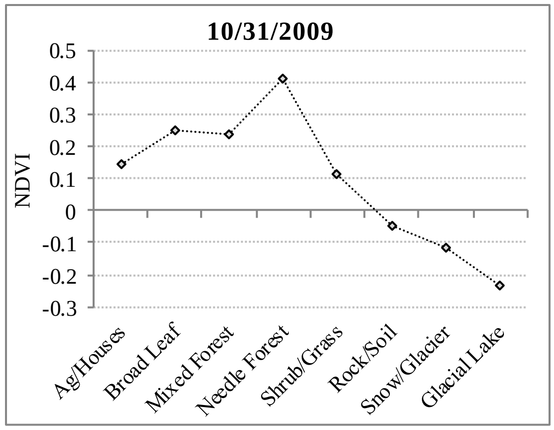
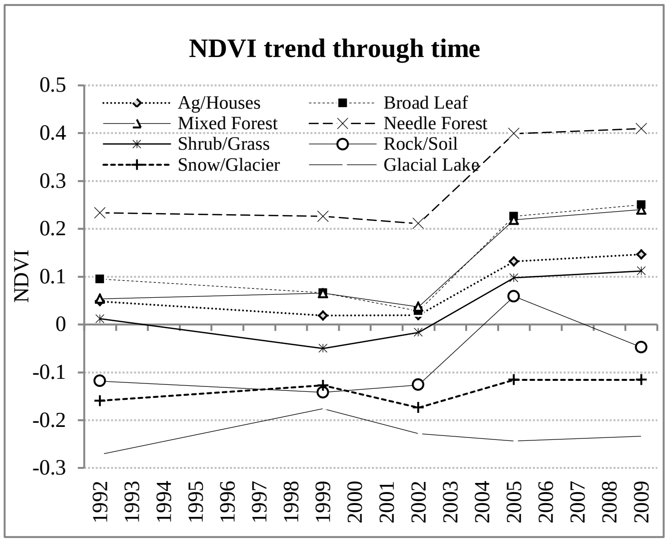


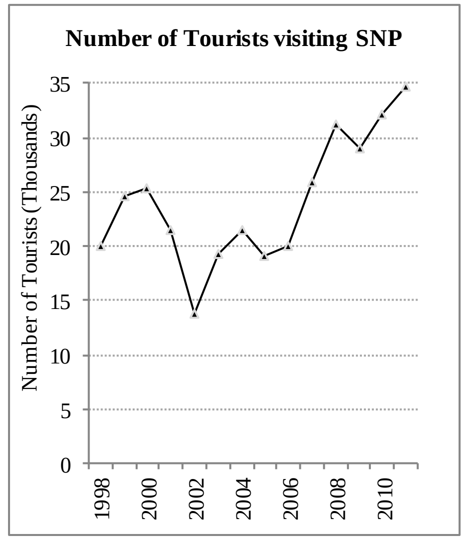
(e)

Figure 4. NDVI for land cover classes a) 1992 b) 1999 c) 2002 d) 2005 e) 2009

NDVI trend graph for 1992-2009 shows overall increase in NDVI for all land cover classes (Figure 5a). There is a sharp increase in the values after 2002. This pattern corresponds to the number of tourists visiting SNP (Figure 5b). This coinciding trend can be explained based on the impact of the Communist Party of Nepal (Maoist) conflict on the tourists and park management. Due to the security issues and the rebellion groups asking for monetary support, the number of tourists significantly declined. Park management became inactive for a few years in late 1990s and early 2000s as park personnel were evacuated during the conflict. This provided freedom for the local people to exploit the forest without any restrictions. When the Maoists won and became involved in the political mainstream, the park management resuscitated its activities to protect natural resources. NDVI for the elevation classes also showed a similar trend (Figure 3). The areas have recovered quickly when the management is back to action due to the settlement of the Maoist issue. Climate changes probably play a significant role as well for the increasing NDVI in snow and ice covered areas.



(a)



(b)

Figure 5. NDVI trend through time based on land cover classes b) Number of tourists visiting SNP in 1998-2011 (Source: DNPWC, Nepal)

5.3 Land Cover Change

There is some fluctuation in the total areas covered by each of these land cover types, but the mixed forest, snow and glacier classes overall show a decreasing trend whereas needle forest, rock and soil have an increasing trend (Figure 6). Significant human disturbances in the lower elevations are the possible causes of declines in mixed forest because this area is the major source of timber for the newly constructed lodges and houses in the park. As there are few human activities in the snow and glacier zones except for climbers, the decrease in ice and snow coverage is likely the result of global warming impacts on the high Himalayas. Glacial moraines are widening due to the breakdown of association between rock, soil and ice. Glaciers are collapsing and depositing debris consisting of bare soil and rock. The reduction in the snow and ice coverage exposes rocks and soil in the higher elevation with the possibility of increasing glacial lake sizes. In addition, the hoofs of the grazing cattle have a great impact on fragile mountain soils forming terraces, creating vegetation loss, and land degradation.

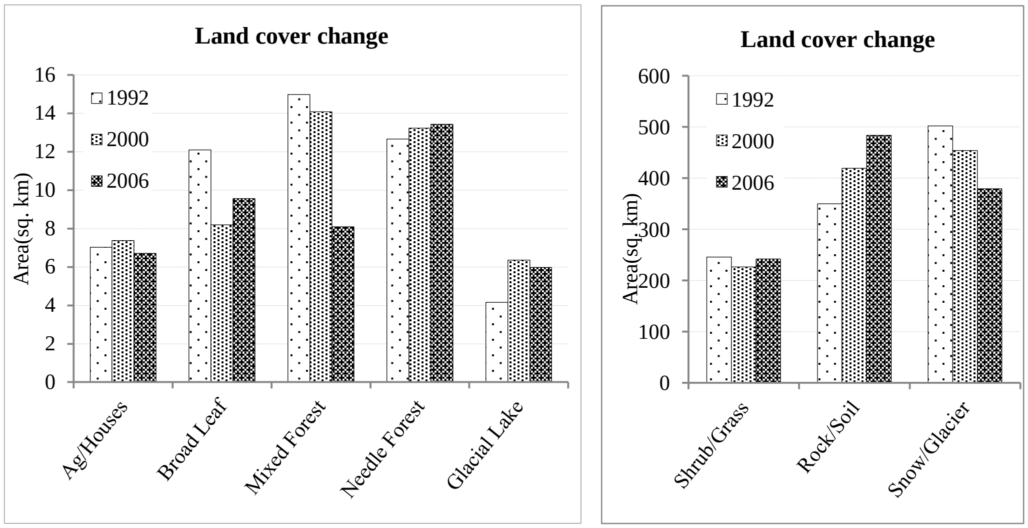


Figure 6. Absolute changes in the area of different land cover classes in SNP (1992-2006)

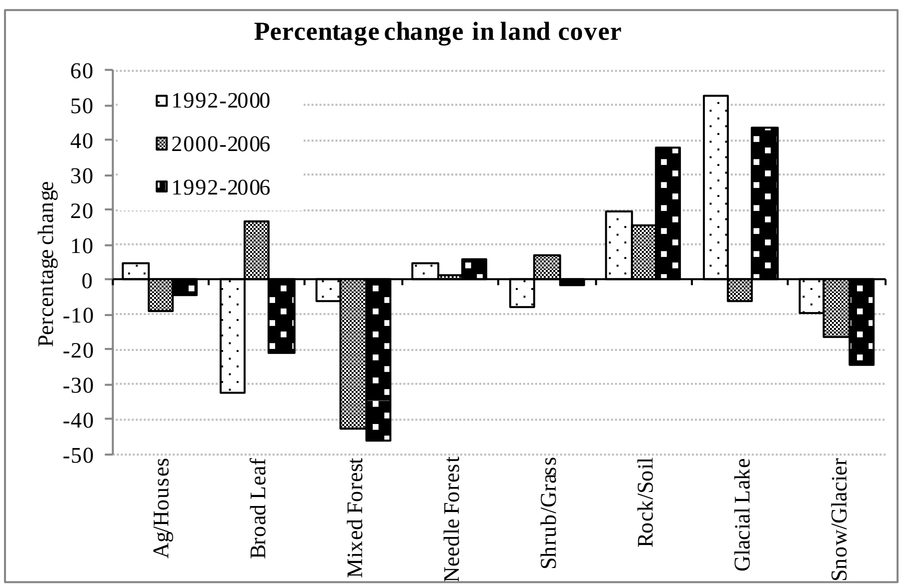


Figure 7. Percentage change in land cover (1992-2006)

The percentage change in the land cover classes (Figure 7) shows that broadleaf and mixed forest areas have been disappeared by a significant proportion. The major factor behind this loss is the wood requirement for new houses and relative availability in more accessible areas. The coverage of needle forests, with the pine and Himalayan spruce, is slightly increasing possibly because of the extensive planting done by the Himalayan Trust (a local CBO) and due to SPCC conservation activities. The areas covered by rocks and soils have increased by 38.13% and glacial lakes have also risen by 43.67%. On the other hand, the areas covered by snow and glacier have been reduced by 24.47%. These three land cover classes are generally interrelated to each other: the melting of snow and ice increases the size of glacial lakes and exposes more rocks and soil.

Table 3: Relative (%) land cover change (1992-2000)

LCC	Ag/ Houses	Broad Leaf	Mixed Forest	Needle Forest	Shrub/ Grass	Rock/ Soil	Glacial Lake	Snow/ Glacier
Ag/ Houses	92.53	0.57	0.16	0.51	3.23	2.99	0.00	0.01
Broad Leaf	0.38	40.67	**13.12**	5.63	**37.05**	3.16	0	0
Mixed Forest	0.14	5.76	51.01	4.07	**30.19**	8.79	0	0.03
Needle Forest	0	4.71	10.11	65.10	**16.74**	3.34	0	0
Shrub/ Grass	0.20	0.58	1.34	1.43	71.04	**25.23**	0.04	0.14
Rock/ Soil	0.08	0.10	0.08	0.04	**11.21**	85.32	0.28	2.89
Glacial Lake	0.02	0	0	0	1.25	**5.52**	88.80	4.41
Snow/ Glacier	0.00	0	0	0	0.27	**11.12**	0.31	88.28

The land cover change matrix for the period of 1992-2000 is presented in Table 3 where grayed cells show the unchanged land cover proportion whereas bold figures show the significant changes among land cover classes during this period. A large portion of the forested areas of the park has been changed to shrub and grass (Figure 10b). In average, more than 25% of the forested areas have been cleared during this period of eight years. Once the forest is cleared, opportunistic species of shrubs and herbs including grass generally invade the exposed areas. These are human induced changes in lower elevation, whereas anthropogenic factors combined with climatic factors have caused change in the higher elevation (Figure 8).

In addition, Alpine scrub and meadows have been turned into the areas with rock and soil with an alarming rate, 25.23% (Figure 10c). Grazing has a huge impact in the alpine areas and Himalayan cattle graze vegetation to dirt and create trail in the alpine slopes. This consequently causes the land failure and exposes additional rock and soil. The warming of climate and subsequent melting of glacier breaks down the association between rocks, dirt and ice. This phenomenon leaves former glaciated regions covered with rock and soil; 11.12% of the snow and glacier have already converted to rock and soil from 1992 to 2000 (Figure 10d). Albeit the percentage change of ice and snow into glacial lakes is small, the absolute change is significant due to the relatively smaller area of the lakes and the even small proportion of ice melting can expand the size of the lakes. Glacial lake outburst floods furthermore expose more rocks and soils. Conversely, some of the areas with rock and soil have changed to shrub and grass possibly due to the recovery after grazing and from new vegetation growing on the recently exposed soil.

Table 4: Relative (%) land cover change (2000-2006)

LCC	Ag/ Houses	Broad Leaf	Mixed Forest	Needle Forest	Shrub/ Grass	Rock/ Soil	Glacial Lake	Snow/ Glacier
Ag/ Houses	78.30	1.45	0.88	1.29	**14.59**	3.04	0.18	0.27
Broad Leaf	0.30	52.23	7.66	7.41	**31.24**	1.17	0	0
Mixed Forest	0.21	14.34	43.46	6.32	**33.83**	1.86	0	0
Needle Forest	0.26	3.50	2.03	72.81	**20.89**	0.51	0	0
Shrub/ Grass	0.19	1.06	0.35	0.73	74.41	**22.94**	0.05	0.27
Rock/ Soil	0.10	0.06	0.05	0.13	**13.93**	83.74	0.12	1.85
Glacial Lake	0	0	0	0	2.62	**11.94**	73.97	11.47
Snow/ Glacier	0	0	0	0	0.84	**17.43**	0.14	81.50

The changes that occurred during 2000-2006 time period correspond to changes in the 1990s. The forested areas have been converted to shrub grass with the highest impact on mixed and broadleaved forest at even accelerated rates (Table 4). Some of the agricultural fields have turned into shrub and grassland because of the local economy turning from farming into tourism and croplands might have been left barren allowing opportunistic plant species to grow. The conversion of areas into shrubs and grasses continued during the 2000s by 22.94% for this six-year period. Also, the change in the areas covered with snow and glacier into rock and soil has accelerated (17.43%). This suggests the increasing impacts of global warming than the previous period. The recovery of shrub and grass into recently denuded areas has also increased. Some glacial lakes dried out and have been defined as rock and soil.

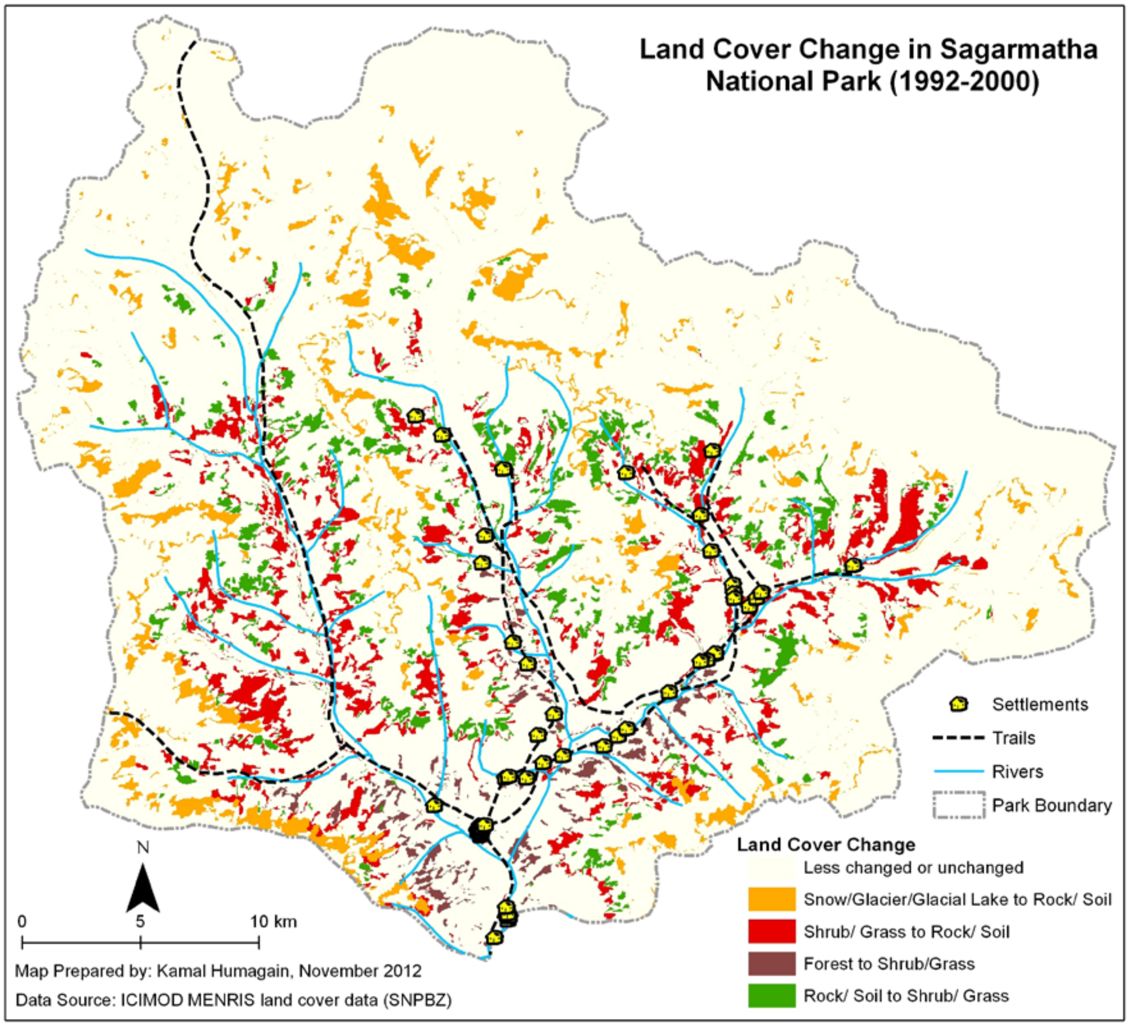


Figure 8. Land cover changes in Sagarmatha National Park (1992-2000)

Figure 8 suggests where major changes occurred during the 1990s. The forested areas are distributed along the river in the lower elevation zones (mostly below 4,000 m). Therefore, most of the deforested areas are located near the settlements and along the trails in the park (Figure 10a). The areas (red), which have turned into rock/soil from shrub/grass, are also mostly close to the trails and the settlements of higher elevation - which includes grazing pastures and areas around the glaciers. Snow/glaciers have changed to rock soil (orange) in the higher elevation whereas some of the areas have changed to shrub/grass (green) from rock/soil in the areas away from human settlements. These areas tend to be farther away from the trails and human settlements at higher elevations. They are likely the areas that were previously glaciers and snows and when glaciers retreated gradually shrubs and grasses took over.

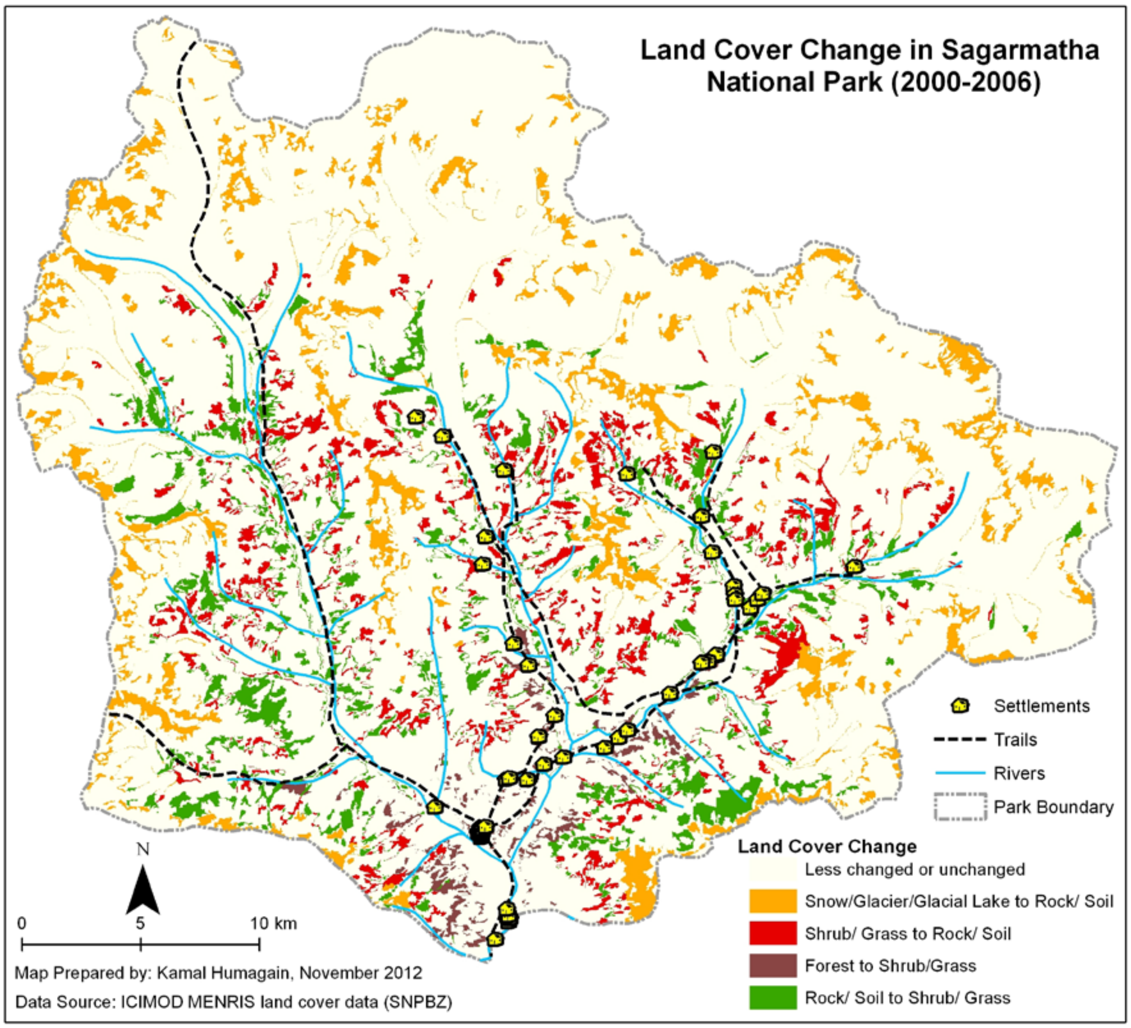


Figure 9. Land cover changes in Sagarmatha National Park (2000-2006)

The changes occurring during 2000-2006 are shown in Figure 9. While comparing Figures 8 and 9, it is obvious that major changes have shifted from lower elevations, along the trails, and nearby settlements to higher elevations, away from the trails and farther from the settlements. As the forests in easily accessible areas were exploited, local people shifted the harvest to the less accessible areas. Same phenomenon may explain the conversion of areas with shrub and grass areas to bare rock and soil due to grazing.

(a) Disturbance around Namche Bazaar

(b) Forest change into Shrub/Grass

(c) Shrub/Grass change into Rock/Soil

(d) Glacier change into Rock/Soil

Figure 10. Land cover changes in Sagarmatha National Park

The invasion of shrub/grass is greater at higher elevations, which might suggest the upward movement of vegetation due to climate change and recovery of the grazed areas. When comparing both maps, it can be observed some areas changed from glaciers to rock/soil from 1992-2000 and then from rock/soil to shrub/grass from 2000-2006. In addition the conversion of snow and glaciated areas to bare rock and soil is also shifting to higher elevations, which might suggest glacial retreat due to climate change. Some of the changes are elucidated by images in Figure 10 (a, b, c and d), which were taken during March 2010 field visit.

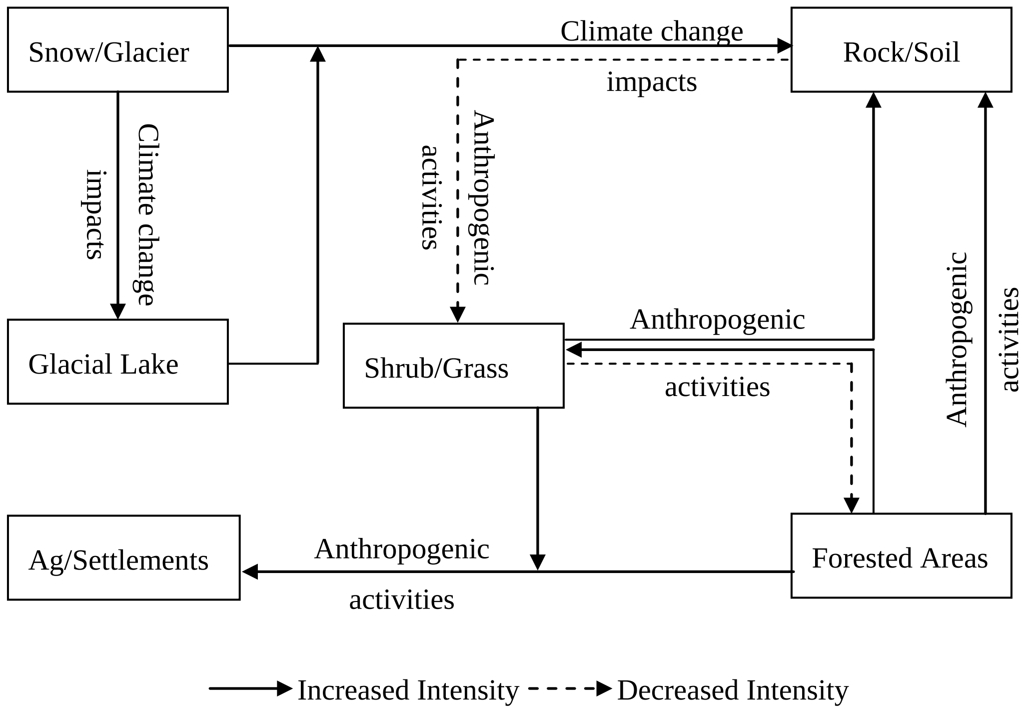


Figure 11. Land cover change model

Based on these changes, a land cover change model is developed to show the changes among land cover classes and their likely causal factors (Figure 11). Melting of ice due to increased global warming converts the areas covered with snow and ice to bare rock and soil whereas the glacial lakes may also expand because of the resulting meltwater. These lakes may burst if lake volumes grow beyond their holding capacity; causing floods which expose rock and soil. Anthropogenic activities are responsible for changing forested areas to shrub/grass or agriculture/ settlements, or even greater disturbances may directly lead to rock and soil exposure. Anthropogenic activities (such as grazing) combined with climate change impacts convert the shrub/grass to rock/soil. These areas might also be converted to farming lands. If there is less human influence and decrease in climate change impacts, the bare rock and soil might recover to gain vegetation. The disturbed areas with shrub and grass may again transform into forests if anthropogenic activities are sufficiently controlled and park management is effective. This model refers to short-term changes in the park; there is possibility of long-term changes such as global cooling cycles in some future scenario may cover the exposed rocks with ice and may freeze the glacial lakes.

5.3 Interview data

Interviews with local residents, hotel owners, works, tourist guides, herders, farmers, local officials and representatives of governmental and non-governmental organizations illustrate local perceptions on land cover change in the park over the years and the possible underlying reasons. The ethnic composition shows Sherpas as highest proportion of the respondents, followed by Rai people (Figure 12a). Though this is a relatively small sample, the situation provides a hint that there is significant presence of non-Sherpa people in the region as compared to the population census 2001 data (>80% Sherpas). A high proportion of people in this region are directly or indirectly related to tourism and most of them make about 300,000 Nepalese rupees (approximately 3,500 USD) or less in a year. The owners of hostels and restaurants can earn far more than that margin if the location of the hotel is in a good place where tourists generally spend multiple days. Typically, they are more interested in making money and a declining proportion of them care about natural resource conservation. SNP management authorities have been implementing conservation activities and regulations, but without much success because of the physiography, accessibility issues, and awareness among the resource users.

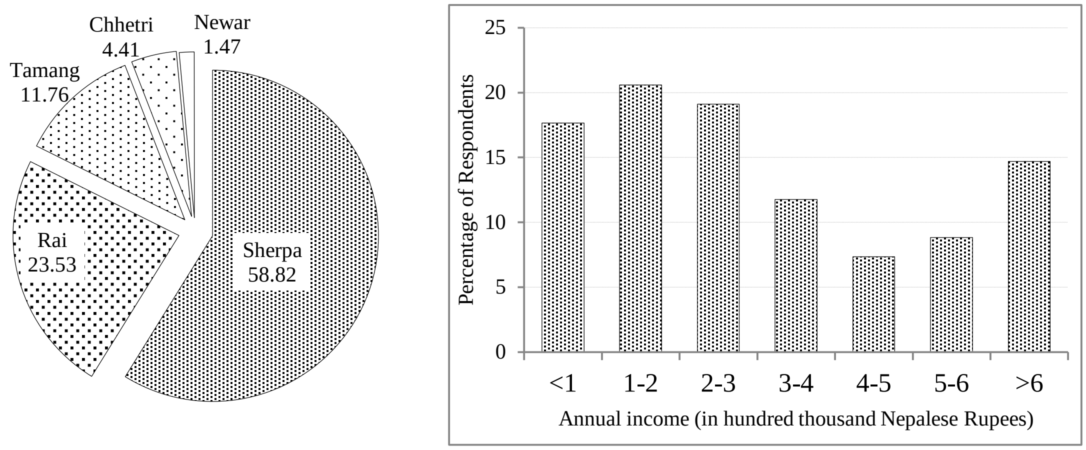


Figure 12. a) Ethnic composition percentage and b) Annual average income of the respondents

The efficacy of park management is questionable to many resource users when discussing conservation of this unique natural mountain ecosystem. Hotel operators, local farmers, and seasonal cattle herders seem satisfied with the management because they think there is no real restriction by SNP – thus allowing uncontrolled harvest of various forest products including timber and firewood and there are no delineated areas for grazing. Because of the extremely cold environment, the supply and demand of firewood is not balanced, resulting the exploitation of the forested and shrub lands for fuels. SNP allows the harvesting of firewood on a rotational basis and provides a few trees to build new and renovate old houses. Some of the communities have started attributing religious significance to the forested areas in order to protect them from more destruction. Environmental changes have been more conspicuous in the past two decades and locals have encountered disastrous natural events such as Glacial Lake Outburst Floods (GLOF). Some of the changes and their possible causes based on the local people's perception are provided in Table 5.

Table 5: Percentage of interviewees' perception on land cover changes and causal factors

Changes	%	Causes	%
Forest degradation	85.29	Human disturbance	70.59
Land failure increased	82.35	Tourism	64.71
Settlements increased	80.88	Park Management	58.82
Increase in resources demand	75.00	No restriction in grazing	57.35
Land use changes	73.53	Outsiders	44.12
Less snow in low elevation	58.82	Climbers	32.35
Glacier melting	55.88	Forest clearance	25.00
Cattle impacts	50.00	Number of cattle increased	25.00

The majority of local people have noticed forest degradation, land failure, increase in settlements and natural resource exploitation. They believe the strongest contributing factors for these changes are human activities, tourism, and the (in)effectiveness of park management. They have witnessed soaring economic value of houses and lands on the tourist trail for past ten years, which corresponds to the increasing number of tourists. This situation creates demand for more workers and thus provides opportunities for outsiders to move into the park seeking employment. Currently, a significant proportion of the hotels and shops are operated by outsiders and non-Sherpa people; although most of the owners are still Sherpas. According to the respondents, the number of hotels, lodges and houses is not sufficient to accommodate the visitors in the peak tourist seasons. As they are turning away from the farm-based economy, the cultivated areas have been transferred to barren ground, and people are prone to construct new buildings and to look for new opportunities in the tourism-based economy.

6. Conclusions

Because of the unavailability of other reference data, collecting real time data is very important while analyzing remotely sensed data. However, field data collection is one of the major challenges for this research because of the rough terrain, remoteness, and less accessibility. In addition, acquiring satellite images for the expected interval of time is a difficult task because of the area covered by monsoon clouds during the growing season. When including only cloud-free images, the temporal intervals of data under consideration were significantly disproportionate. However, stakeholder's perception and an ample number of ground control points has aided validating the results in spite of this limitation.

This study adopted an integrative methodology of spatial data and ethnographic interviews to explain land cover changes in the mountainous areas of Nepal. Sagarmatha National Park has been through several notable changes during the period of 1972-2009. The NDVI trend in elevation classes shows an overall increase in the NDVI values for all elevation classes. As a qualitative measure, this analysis shows the shrinkage in the area within the park covered by ice and snow. As a consequence, glacial lakes and areas covered by rock and bare soil are expanding in size; which is supported by an NDVI analysis based on land cover data for a period of 1992-2009. Based on ICIMOD data, the quantitative analysis shows a loss of 24.47% of the snow and glacier and an increase of 43.67% of glacial lake and 40.31% of rock and soil for the period of 1992-2006. Almost one-fifth of the forested areas in the park has been lost during the same period. Once the trees are cleared, shrubs and grasses cover the disturbed area or the areas are converted into agricultural fields or potentially only rock and soil is left behind. The changes at lower elevations can be explained by activities of local people as they cope with increasing tourism and park management: whereas these factors cannot merely explain the changes in the high elevation. The only other possible explanation for alteration of these high mountain environments is increasing global temperature.

Global warming causes the melting of glaciers in the region; which in turn expands the size of glacial lakes. Once the glaciers melt away, debris of rock and soil are exposed, which widens the size of glacial moraines. In addition, cattle overgrazing creates trail in alpine slopes and eventual land failure exposes rocks and bare soil. These two factors can explain the significant increase in the areas covered by rocks and soil. On the contrary, declining human intervention and effective park management may help allow the recovery of denuded alpine slopes and deforested areas that are near the settlements and trails. Given that global factors are also responsible for the environmental changes, local people are not educated about global climate change and its impact on the Himalayas.

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APPENDIX II: Ground Control Points Data Table

Ground Control Points Data Table - Part I

Table

OnlyParkGCP

GCPNum	GPSErro	Lat_1	Long_1	DateTime	Elev	PicNums	AspDir	AspDeg	SlopeDeg	LandCode	LandCover	Classes	UCClose	MCClose	GCHerb
019	20	27.756701	86.710193	29-SEP-09 14:25:41	2705	6715	W	270	0	GST	Grass with Scattered Trees	Shrub/Grass	20	0	75
020	27	27.761236	86.712344	29-SEP-09 14:41:30	2735	6726	SE	160	80	PF	Pinus Forest	Needle Forest	70	0	80
021	12	27.762135	86.717393	29-SEP-09 15:00:12	2731	6736	SE	150	0	S	Settlements	Ag/Houses	30	0	45
022	6	27.764114	86.720717	29-SEP-09 15:14:22	2741	6746	NoData	NoData	0	BR	Bridge	Bridge	0	0	0
023	13	27.764393	86.722046	29-SEP-09 15:19:23	2755	6756	SW	220	35	SLTR	Scattered Large Trees with Regrowth (Shrub/	Mixed Forest	40	80	5
024	7	27.768919	86.723123	29-SEP-09 15:33:57	2799	6766	S	190	5	S/Ag	Settlements/Agriculture	Ag/Houses	20	20	40
025	12	27.770156	86.723705	29-SEP-09 15:46:44	2836	6776	SW	240	5	S/SLTR	Settlements/Scattered Large Trees with Regro	Ag/Houses	30	0	10
026	0	27.771204	86.72315	29-SEP-09 15:56:27	2841	NoData	NoData	NoData	0	S	Settlements	Ag/Houses	0	0	0
027	0	27.77372	86.722414	30-SEP-09 8:41:27	2850	6786	NoData	NoData	0	S	Settlements	Ag/Houses	0	0	5
028	9	27.776126	86.722086	30-SEP-09 8:53:58	2803	6796	SW	320	0	Ag/MF	Agriculture/Mixed Forest	Ag/Houses	20	15	20
029	0	27.776693	86.721585	30-SEP-09 9:03:33	2804	6805	NoData	NoData	0	BR	Bridge	Bridge	0	0	0
030	9	27.780526	86.722733	30-SEP-09 9:24:23	2810	6815	NoData	NoData	0	BR	Bridge	Bridge	0	0	0
031	7	27.785031	86.721914	30-SEP-09 9:36:57	2831	6825	SW	230	70	FP	Floodplain (rock dominate, cobbles)	Rock/Soil	15	30	30
032	8	27.788104	86.719591	30-SEP-09 9:53:57	2853	6827-36	NoData	NoData	0	FP	Floodplain (rock dominate, cobbles)	Rock/Soil	5	20	20
033	7	27.790043	86.71888	30-SEP-09 10:06:48	2895	6846	NoData	NoData	0	BR	Bridge	Bridge	0	0	0
034	7	27.790542	86.718087	30-SEP-09 10:20:35	2950	6856	SE	130	65	PF	Pinus Forest	Needle Forest	35	25	65
035	6	27.791577	86.716944	30-SEP-09 10:36:36	3031	6866	S	180	80	Trans	Transition between Forest and Disturbed Area	Mixed Forest	20	10	70
036	5	27.792987	86.715642	30-SEP-09 10:51:42	3102	6876	SW	200	70	PF	Pinus Forest	Needle Forest	60	20	85
037	4	27.793544	86.715874	30-SEP-09 11:04:31	3138	6886	SW	250	55	HD/PF	Human Disturbed/Pine Forest	Needle Forest	65	25	20
038	9	27.795643	86.714079	30-SEP-09 11:20:03	3208	6896	SE	110	70	PF	Pinus Forest	Needle Forest	20	80	20
039	8	27.797931	86.711576	30-SEP-09 11:36:25	3290	6906	W	270	65	PF	Pinus Forest	Needle Forest	20	90	10
040	6	27.801442	86.711385	30-SEP-09 11:52:33	3357	6916	SW	230	65	S/Ag	Settlements/Agriculture	Ag/Houses	0	15	20
041	6	27.802327	86.710065	30-SEP-09 12:07:28	3384	6926	SW	210	70	HD/DSR	Human Disturbed/Disturbed Shrubs and Regro	Shrub/Grass	5	85	25
042	0	27.80494	86.711161	30-SEP-09 12:18:54	3430	NoData	NoData	NoData	NoData	S	Settlements	Ag/Houses	0	0	0
043	5	27.804693	86.708281	30-SEP-09 13:06:55	3483	6936	E	100	75	DSR/HD	Disturbed Shrubs and Regrowth – large shrub	Shrub/Grass	0	30	50
044	6	27.803471	86.706387	30-SEP-09 13:17:13	3519	6946	SE	160	30	HD	Human Disturbed	Ag/Houses	0	0	0
045	6	27.80674	86.704673	30-SEP-09 13:49:49	3546	6957	SW	230	70	ADS	Alpine Dwarf Shrub	Shrub/Grass	0	15	30
046	7	27.807612	86.703516	30-SEP-09 13:58:42	3549	6967	SE	160	70	BSG	Boulder Shrub Grassland	Shrub/Grass	0	35	40
047	8	27.808516	86.701187	30-SEP-09 14:10:25	3540	6978	SW	180	75	OF	Open Forest	Mixed Forest	90	5	50
048	8	27.810043	86.698847	30-SEP-09 14:19:36	3543	6988	SW	220	75	AF	Abies Forest	Needle Forest	80	20	65
049	0	27.810775	86.697976	30-SEP-09 14:27:02	3547	NoData	NoData	NoData	NoData	PF	Pinus Forest	Needle Forest	0	0	0
050	7	27.812186	86.694423	30-SEP-09 14:33:50	3516	6999	S	190	70	AF	Abies Forest	Needle Forest	65	50	70
051	4	27.812565	86.691452	30-SEP-09 14:50:52	3512	7009	SW	235	20	S/Ag	Settlements/Agriculture	Ag/Houses	5	0	30
052	6	27.812812	86.68983	30-SEP-09 14:58:28	3494	7019	SW	230	75	AF	Abies Forest	Needle Forest	90	35	50
053	6	27.813714	86.689185	30-SEP-09 15:05:44	3482	7029	SW	260	70	HD/DSR	Human Disturbed/Disturbed Shrubs and Regro	Shrub/Grass	40	75	40
054	5	27.80613	86.715915	01-OCT-09 8:53:32	3541	7039	S	190	60	AG	Agriculture	Ag/Houses	0	30	30
055	5	27.805382	86.718957	01-OCT-09 9:06:14	3554	7049	S	180	60	ADS	Alpine Dwarf Shrub	Shrub/Grass	0	0	10
056	6	27.807582	86.719671	01-OCT-09 9:16:51	3547	7059	SE	160	60	ASST	Alpine Shrub with Scattered Trees	Shrub/Grass	5	5	40
057	5	27.807871	86.721007	01-OCT-09 9:26:15	3570	7069	SE	150	55	ADS	Alpine Dwarf Shrub	Shrub/Grass	5	0	40
058	6	27.811756	86.723601	01-OCT-09 9:45:06	3562	7079	E	130	70	ASST	Alpine Shrub with Scattered Trees	Shrub/Grass	10	10	30
059	8	27.814436	86.727747	01-OCT-09 10:00:39	3587	7090	E	95	60	ATS	Alpine Tree/Shrub	Needle Forest	65	80	50
060	8	27.817997	86.731705	01-OCT-09 10:18:29	3587	7101	E	120	80	CG/FR	Cliff with Grass/Forest Recovery	Rock/Soil	20	0	40

1 (0 out of 518 Selected)

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Ground Control Points Data Table - Part II (continued from previous page)

Table

OnlyParkGCP

GCHerb	GCShrub	GCLitter	GCIce	GCRock	GCWater	GCSoil	Fire	Grazing	Wood	Limbs	Digging	Erosion	Disease	Drought	Other
75	20	0	0	5	0	0	0	5	0	0	0	0	0	0	moved gross-lawn E, pasture but small, some houses
80	0	0	0	15	0	5	0	5	3	5	0	0	0	0	pine 9651-57, open forest, 5, 8, 9 unknown
45	20	0	0	25	0	10	0	0	5	5	4	0	0	0	unknown Rosa 9660-3, houses and several gardens, pine above
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Bridge over large river with major flood plain damage/1985-GLOF Scar
5	90	0	0	0	0	5	0	2	5	5	0	0	0	0	saplings and seedlings everywhere, major flood plain damage
40	20	0	0	30	0	10	0	2	4	5	3	0	0	0	houses and gardens, lawn
10	20	0	0	40	0	30	0	0	5	5	5	0	0	0	new 10 inch pipe E-W on edge of Morjo, edge of plateau
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Kailash Guest House
5	5	0	0	90	0	0	0	0	0	0	0	0	0	0	Border Gate- National Park
20	15	5	0	10	0	50	0	5	5	5	3	1	0	0	pine saplings, near bridge, flat garden/pasture/hill, Rho ant bushes
0	0	0	0	0	100	0	0	0	0	0	0	0	0	0	NoData
0	5	0	0	20	75	0	0	0	0	0	0	0	0	0	River in flood plain, flood damage
30	10	0	0	50	5	5	0	0	0	4	0	5	0	0	ridge, flat and then 70 degree slope, pine saplings/seedlings abundant
20	10	0	0	45	5	20	0	0	3	4	0	5	0	0	on a FP shelf, lower FP scared rock, seed upper part
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	100m above flood plain, Y intersection of rivers
65	10	0	0	25	0	0	0	0	2	3	0	0	0	0	steep open pine woodland with some dying trees from bottom up
70	10	0	0	20	0	0	0	0	0	0	0	1	0	0	old man 1982, no trees on trail, 80's over grazed above
85	10	0	0	5	0	0	0	0	0	4	0	0	3	0	steep slope pine regrowth, splotchy decrease gradually
20	5	0	0	5	0	70	0	0	2	4	4	2	0	0	Everest first view platfrom, erosion from cleaning of that view
20	30	50	0	0	0	0	0	0	0	1	0	0	0	0	pine regrowth everywhere, very thick seedlings and sapling
10	20	70	0	0	0	0	0	0	0	0	2	0	2	0	pine regrowth abundant, Ist Abies
20	10	0	0	20	0	50	0	5	5	5	5	2	0	0	terraces up and down hill with building on trail, Ist building
25	70	0	0	5	0	0	0	5	5	5	0	0	0	0	trail forced to halt grazing, slow regrowth
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	Hotel Camp de Base, Namche bazaar
50	30	0	0	5	0	15	0	0	0	0	0	0	0	0	NoData
0	20	0	0	20	0	60	0	0	0	0	5	5	0	0	Juniper seedling, new platform this year
30	30	0	0	40	0	0	0	3	5	5	0	3	0	0	Rock with small scrub and flowers, more rocks to W in pixel
40	35	0	0	25	0	0	0	3	5	5	0	2	0	0	NoData
50	5	35	0	0	0	15	0	4	3	4	0	0	0	0	NoData
65	15	20	0	0	0	0	0	0	0	0	0	0	0	0	NoData
0	0	0	0	0	0	0	0	2	1	4	0	0	0	0	Trail junction to Syanboche Air station, small trail joining main trail uphill
70	20	5	0	0	0	0	0	3	2	2	0	0	0	0	thinned forest with Rho arb comimg in
30	0	0	0	20	0	50	0	5	5	5	4	3	0	0	edge of settlement near Stupa
50	0	50	0	0	0	0	0	5	3	5	0	2	0	0	NoData
40	50	10	0	0	0	0	0	3	4	5	0	3	0	0	edge of forest/shrub/to AG, all W is AG growing for HM
30	15	0	0	5	0	50	0	3	5	5	2	3	0	0	edge of Namche AG area, near last house
10	75	0	0	5	0	10	0	5	5	5	0	4	0	0	heavy erosion everywhere from grazing, no forbs left
40	30	0	0	20	0	10	0	5	5	5	0	4	0	0	dry drainage only during worst storms, more rocky trees, shrubs NE
40	50	0	0	0	0	10	0	5	5	5	0	2	0	0	lots of pine seedlings, Jun and Ab seedlings, grazing terraces
30	50	0	0	15	0	5	0	5	4	3	0	2	0	0	grazing terraces, ridge with rocks, West below Stupa is thick shrubs/
50	40	10	0	0	0	0	0	2	2	4	0	2	0	0	erosion channel, vetrtical band of trees, erosion channel to N
40	20	0	0	40	0	0	0	5	0	0	0	3	0	0	grazing terraces, grazing terraces, scattered pine regrowth, NE aspec

0 (0 out of 518 Selected)

OnlyParkGCP

APPENDIX III: Sagarmatha National Park in Pictures

Mount Everest (8,848 meters)

Park headquarters (Namche)

Khumjung village (One of the dense settlements)

Trails created by cattle grazing

Melting Khumbu glacier and nearby hostels

Expanding glacial moraine

APPENDIX IV: List of Major Interview Questions

The questions used in informal interviews were grouped and presented here after modification:

- What is your name? Where do you live? Where are you from?
- What is your family size?
- What is your profession? What is your annual income?
- Are you satisfied with this profession and income?
- For how many months do you stay in the park in a year?
- What changes have you seen in the park since you started coming here?
- Are the forested areas increasing or decreasing?
- Have you noticed about the glacier melting? What about the glacial lake?
- What are the major changes in the park? (Options provided: forest degradation, land failure, Settlements, natural resources demand, land use changes, snowing duration and frequency, cattle impacts, glacier melting, or any other if they want to say)
- What are the major causes for these changes (Options provided: human disturbance, tourism, park management, grazing, outsiders, climbers, forest clearance, increase in the number of cattle, or any other if they want to say)
- Are you satisfied with the park management?
- How about CBOs? Are they organizing activities that are beneficial for the park and livelihood?
- Do you have any other things to say about changes in the park?

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CURRICULUM VITAE

KAMAL HUMAGAIN

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EDUCATION

Masters of Science in Geoscience, GPA 4.0/4.0 2010-2012
Department of Geography and Geology
Western Kentucky University, Bowling Green, KY

Graduate Certificate in Geographic Information Science, GPA 4.0/4.0 2010-2012
Western Kentucky University, Bowling Green, KY

Masters of Arts in Sociology, First Division 2006-2008
Tri-Chandra Multiple Campus
Tribhuvan University, Kathmandu, Nepal

Masters of Science in Botany, First Division 2004-2006
Central Department of Botany
Tribhuvan University, Kathmandu, Nepal

Bachelor of Science in Botany, Second Division 2000-2004
Tri-Chandra Multiple Campus
Tribhuvan University, Kathmandu, Nepal

GIS AND OTHER COMPUTER SKILLS

- ArcGIS Desktop (9.x and 10) core applications (ArcMap, ArcCatalog, ArcToolbox, and ArcScene).
- Manage spatial data, geo-reference and digitize scanned maps/ images, format conversion and editing tasks on vector and raster data layers
- Creating geo-processing models in ArcGIS Model Builder and coding in Python
- 3D modeling in ArcScene with TINs and creating 3D marker symbols.
- Using spatial statistics tools for analysis
- ArcGIS Desktop Extensions: Network Analyst, Spatial Analyst, Geostatistical Analyst, and 3D Analyst
- ERDAS Imagine (2009 and 2010)
- Pathfinder Office and Trimble GPS (mapping grade)

- Creating large format maps produced by HP DesignJet Z6100ps
- Microsoft Office Suite, Adobe Photoshop, Adobe Dreamweaver, S-Plus statistical software, and Google Sketchup

EXPERIENCE

Graduate Research Assistant **2010-2012**

Western Kentucky University, Bowling Green, KY

- Acquiring vector and raster data and performing land cover classification based on ground data/vegetation cover using ERDAS Imagine and ArcGIS
- Analyzing spatial patterns of natural and human disturbances using spatial statistical applications in ArcGIS
- Assisting students in the lab to conduct different class research projects and lab exercises for remote sensing course (Graduate and Undergraduate)

Graduate Research Assistant **2011-2012**

Hoffman Environmental Research Institute, Bowling Green, KY

- Working in research projects on groundwater quality in Kentucky
- Assisting in data collection in the field and later transferring to computer and analyzing using different software packages

Research Assistant **2009-2010**

Central Department of Botany, Tribhuvan University, Kathmandu, Nepal

- Assisting Head of the Central Department of Botany to establish GIS and Remote Sensing Lab in the department
- Assisting Fulbright Professor (GIS/Remote Sensing) to conduct training on GIS and Remote Sensing applications in Natural Resource Management for graduate students and faculty
- Organizing field trip to train graduate students in field data and herbarium samples collection using GPS and customized data tables
- Visiting several protected areas to collect ground data on climate change impact on vegetation and local community
- Maintaining GIS/Remote Sensing lab in terms of hardware and software for smooth running for graduate students and staffs

Project Coordinator **2008-2009**

Ethnobotanical Society of Nepal, Kathmandu Nepal

September 2008-August 2009

- Planning and organizing different activities for the project **“**Participatory conservation of threatened medicinal plants and their habitats” funded by Plantlife International
- Preparing project layout and planning different activities for the project
- Organizing several field trips to collect data on important medicinal plants and their habitat
- Organizing on-site training programs to raise awareness among local people for conservation of important medicinal plants and their habitats
- Guiding two graduate students in collecting field data, analyzing and developing theses

Research Assistant **2006-2008**

Ethnobotanical Society of Nepal, Kathmandu Nepal

- Assisting in the field and in the lab for the projects “Plant biodiversity inventory, identification of hotspots and conservation strategies for threatened species and habitats in Kachenjungha-Sighalila Ridge, Eastern Nepal” (funded by CEPF through WWF Nepal) and “Community based conservation of medicinal plants in Rasuwa, Nepal Himalaya” (funded by Plantlife International)
- Assisting to organize field trips to collect plant samples and their ecological distribution
- Collecting data for the botanical inventory for the biodiversity hotspots based on ethnobotanical knowledge
- Organizing field data, managing herbarium specimens and performing ecological and taxonomical analysis
- Assisting in writing project reports and developing proposal for other projects

RESEARCH PAPERS AND REPORTS

- Humagain K., & Shrestha, K. K. (2009). *Participatory conservation of threatened medicinal plants and their habitats in Rasuwa district, Central Nepal*. Project report submitted to Plantlife International, UK.
- Humagain, K. (2010). *Socio-economic Status of the Tamang Communities in the Northern villages of Rasuwa District, Central Nepal*. M.A. Thesis. Submitted to Department of Sociology and Anthropology, Tri-Chandra Multiple Campus, Tribhuvan University, Kathmandu, Nepal.
- Humagain, K., & Shrestha, K. K. (2009). Medicinal plants in Rasuwa district, Central Nepal: trade and livelihood. *Botanica Orientalis*. 6:39-46.
- Humagain, K., & Shrestha, K. K. (2008). *Medicinal Plants of Rasuwa district, Central Nepal: Status, trade and Conservation.* M.Sc. Thesis. Submitted to Central Department of Botany, Tribhuvan University, Kathmandu, Nepal.

- Shrestha, K. K., Kunwar, R. M., Dhamala, M. K., Humagain, K., Pandey, J., & Khatri, N. B. (2008). Conservation of Plant Resources in Kanchenjungha-Singhalila ridge, Eastern Nepal. *Nepal Journal of Plant Sciences* 2.

ABSTRACTS IN CONFERENCES

- Humagain, K., & All. J. D. (2012). Measuring land use and land cover change using satellite imagery in Sagarmatha National Park, Nepal. Paper presented at The 42nd Annual WKU Student Research Conference, March 24, Western Kentucky University, Kentucky.
- Humagain K., Hutchison, S. T., All, J. D., & Gourley, R. D. (2011). Application of remote sensing data to describe spatiotemporal characteristics of fire in Nepal. Poster presented at 66th Annual Meeting of the South East Division of American Association of Geographers (SEDAAG), November 20-22. Savannah, GA.
- Humagain, K. & All, J. D. (2011). Land use and land cover change in Sagarmatha National Park (1979-2009). Paper presented at The 97th Annual Meeting of the Kentucky Academy of Science (KAS), November 4-5, Murray State University, Kentucky.
- All, J. D., Miles, L., Humagain, K., & Oris, W. (2011). Assessing relative accuracies of ASTER and SRTM DEM datasets in the Himalayan Mountains. The Association of American Geographers Annual Meeting Abstract Volume, April 12-16. Seattle, Washington.
- Humagain, K. (2011). Biogeographical trends along elevational gradient in Nepal. Paper presented at The 41st Annual WKU Student Research Conference, March 26, Western Kentucky University, Kentucky.
- Humagain, K. (2010). Impact of tourism and climate change in Sagarmatha National Park, Nepal. Paper presented at The 96th Annual Meeting of Kentucky Academy of Science, Western Kentucky University, Kentucky.

MISCLLENEOUS PUBLICATIONS

- 2007. Photographs (including cover photo) in the Project and Workshop Report: Identification and conservation of important plant areas for medicinal plants in the Himalaya http://www.plantlife.org.uk/uploads/documents/IPAHim_MP_FINAL_REPORT.pdf
- 2007. Photograph in Critical Ecosystem Partnership Fund (CEPF) bulletin http://www.cepf.net/Documents/wwfcepf_bulletin3.pdf
- 2007. Photographs in WWF web bulletin http://www.wwfnepal.org/media_information/news/?119340/A-botanists-trails

AWARDS, SCHOLARSHIPS AND HONORS

- Graduate full tuition waiver, scholarship and assistantship for M. S. in Geoscience by Department of Geography and Geology, Western Kentucky University, Bowling Green, KY. 2010-2012.
- Graduate Research Competition Award (First Place) at 97th Annual Meeting of Kentucky Academy of Science at Murray State University, November 5, Kentucky. 2011.
- Full Scholarship by Rotary Club of Gananoque (Canada) via Rotary Club of Bhaktapur for three years for M. Sc. in Botany. 2004-2006.
- Gold Medal in School Leaving Certificate (SLC) Examination for obtaining the First position among all the students in Kavre District, Nepal. 1997.

ABBREVIATIONS

Ag- Agriculture

CBO- Community Based Organization

DNPWC- Department of National Parks and Wildlife Conservation

ETM- Enhanced Thematic Mapper

GCP- Ground Control Point

ICIMOD- International Center for Mountain Research and Development

IPCC- Intergovernmental Panel on Climate Change

KACC- Khumbu Alpine Conservation Committee

LCLUC- Land Use and Land Cover Change

MSS- Multispectral Scanner

NDVI- Normalized Difference Vegetation Index

NIR- Near Infrared

SBC- Sagarmatha Base Camp

SNP- Sagarmatha National Park

SNPBZ- Sagarmatha National Park and Buffer Zone

SPCC- Sagarmatha Pollution Control Committee

TM- Thematic Mapper

UN- United Nations

UNEP- United Nations Environment Programme

UNESCO- United Nations Educational, Scientific and Cultural Organization

WMO- World Meteorological Organization